US Army Corps of Engineers®
Engineer Research and Development Center

Net Zero Water for Army Installations

Considerations for Policy and Technology

Elisabeth M. Jenicek, Laura E. Curvey, Annette L. Stumpf, and Kelly Fishman

Introduction

Fresh water is a fundamental requirement of life on earth. Though 70 percent of the planet's surface is covered in water, less than 3 percent is fresh; the rest is undrinkable seawater. Most of this fresh water is contained in glaciers and ice caps. The uneven global distribution of fresh water leaves one in six (1.1 billion) people without access to this necessity (WHO/UNICEF 2005). Water is such a critical resource that it was included in Millennium Development Goal 7, which is to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" (United Nations 2000). As world population grows —estimated to become more than 8 billion by 2030— so too will the urgency of water security.

Increasing demand, degraded supply, uneven distribution, and aging infrastructure are a few of the issues affecting water security—the capacity of a population to ensure that they continue to have access to potable water. Global climate change is projected to affect both water supply and distribution. Most large non-renewable reserves of groundwater are shared by neighboring nations and almost half of the Earth's land surface lies within international river basins (UNESCO 2010 and UNEP 2002). The world's water is a collective resource and the potential for conflict is real.

The US Army is vulnerable to the same issues of water supply and demand that jeopardize global water security. Providing the required amount of clean fresh water where it is needed is increasingly difficult. The conditions that threaten water availability are the aging state of water infrastructure, generalized population growth (especially in regions containing key Army installations), increased water demands for energy, and uncertain, but generally agreed upon regional effects of global climate change. The complexity of water compacts, treaties, and agreements is another challenge for installations. In the coming years, the effects of water scarcity will be more severe in certain locations and this will be reflected in increasing costs.

These global drivers of water security have driven increasing interest in preserving this finite resource. On the Federal level, legislation and executive orders with increasingly rigorous water conservation requirements have emerged over the last decade. The Army has promulgated these requirements through policy and regulation and taken it a step further in establishing challenging targets for installations to achieve "Net Zero Water" (NZW). NZW is an emerging concept that is analogous to net zero energy, simply stated: "The net zero water strategy balances water availability and use to ensure sustainable water supply for years to come" (US Army ASA[IE&E] 2011). In many cases, Army installation staff have already implemented easy fixes—the "low hanging fruit" of state-of-the-shelf technologies. Large reductions in water use will require taking a holistic approach that includes policy, technology, education, partnering with others, and strong command emphasis.

Integrated water management toward achieving NZW can help meet Army water reduction goals with additional benefits of conserving highly treated drinking water, providing a locally-controlled water supply, decreasing diversion of water from sensitive ecosystems, decreasing wastewater discharges, and reducing and preventing pollution. Implementation of interior water-saving technologies alone can cut overall water consumption by 30 percent or more, with payback periods as short as 3 years with certain technologies. Treating water to non-potable, versus potable, standards uses less energy and usually produces fewer waste products that must be disposed of. Additional benefits include relieving stress on water infrastructure by reducing water volumes; regulatory mandates and incentives, such as water rate and tax subsidies; and shifting expectations toward sustainability. Army installations in water-stressed regions compete with local communities for resources; therefore, best practices in water use also benefit the Army by fostering good community relations.

This document describes issues that affect Army installation water security, explores concepts of NZW and early efforts to achieve it, and identifies a number of policies and technologies that should be included in a program to achieve NZW. Subsequent sections of this report recommend how the pieces of the NZW puzzle should be evaluated in developing policy, plans, and programs.

National Water Trends

Water demand

The driving forces and pressures on water resources include both naturally occurring and human actions. Anthropogenic driving forces include population growth, demographic change including migration from rural to urban areas, increase in standard of living, competition between users, land-use change, and pollution of water resources. The natural variability of climate-induced distribution and occurrence of water make it difficult to predict the resource. One forecast presents a “business as usual” demand in 2030 of 6900 billion m^3. This compares to current global use of 4500 billion m^3 and is 40 percent above current, accessible, reliable supply (2030 Water Resources Group 2009).

The US Army recently experienced unprecedented growth, undergoing the largest organizational change since World War II. It is estimated that fully one-third of the forces have been restationed by 2011, an action that affected 380,000 soldiers and their family members. In addition, total Army strength grew by 74,200 troops. This transformation triggered 743 new building construction projects at a cost of $66.4B (Balocki 2008). Now, however, the Army may expect reductions in troops to cut $400 billion from the Pentagon budget by 2023 (DefenseNews.com 2011).

Groundwater depletion

Water tables are falling on every continent. Aquifer depletion is a global problem that has emerged in the last half century. It is only during this time period that the pumping capacity has existed to deplete aquifers. The size of the world water deficit—the amount of over-pumping in the world—using data for India, China, the Middle East, North Africa, and the United States—is estimated to be 160 billion tons of water, which equals 160 billion cubic meters (Postel 1999). The United State’s portion of the water shortfall is about 2700 billion gal/yr (10.2 billion m^3/yr), about 7 percent of the total.

Groundwater depletion is an issue of great concern in the Southwest and High Plains, even though increasing demand has overstressed aquifers in many areas of the United States. Groundwater depletion can occur at scales from a single well to an entire aquifer system. Adverse effects in the Atlantic Coastal Plain include reduced base flow of streams and saline movement inland. In West Central Florida, groundwater development caused saltwater intrusion and sinkholes. Groundwater decline and subsidence are the effects along the Gulf Coastal Plain. Water level declines have also been noted in the High Plains, Pacific Northwest, and Desert Southwest (Figure 1). Long-term pumping of groundwater in the Chicago-Milwaukee area has lowered groundwater levels by as much as 900 ft (274 m) (Reilly et al. 2008).

Climate change

Climate change is one of the factors that make assessing water security difficult. Global climate change is projected to have a variety of effects on water resources including influences on supply reliability, flood risk, health, agriculture, energy, and aquatic systems. The main climate drivers that affect water are changing temperature and precipitation and rising global sea levels (Brekke et al. 2009). Increasing global temperature has the immediate effect of producing higher evaporation rates, thereby drying soils, increasing irrigation requirements of agriculture, and reducing reservoirs of surface water. Aquifer recharge will also slow, thereby accelerating groundwater depletion.

A range of changes to weather patterns are anticipated. These include both increased flooding and drought, sometimes within the same region, as storm events become larger and more seasonal. Coastal freshwater supplies are expected to decrease and become vulnerable to saltwater intrusion. Reduced snowpack and glacier melt is expected to diminish water availability for seasonal demands (McKeown and Gardner 2009). In addition, earlier snowmelt will reduce surface water availability for late-season agricultural needs.

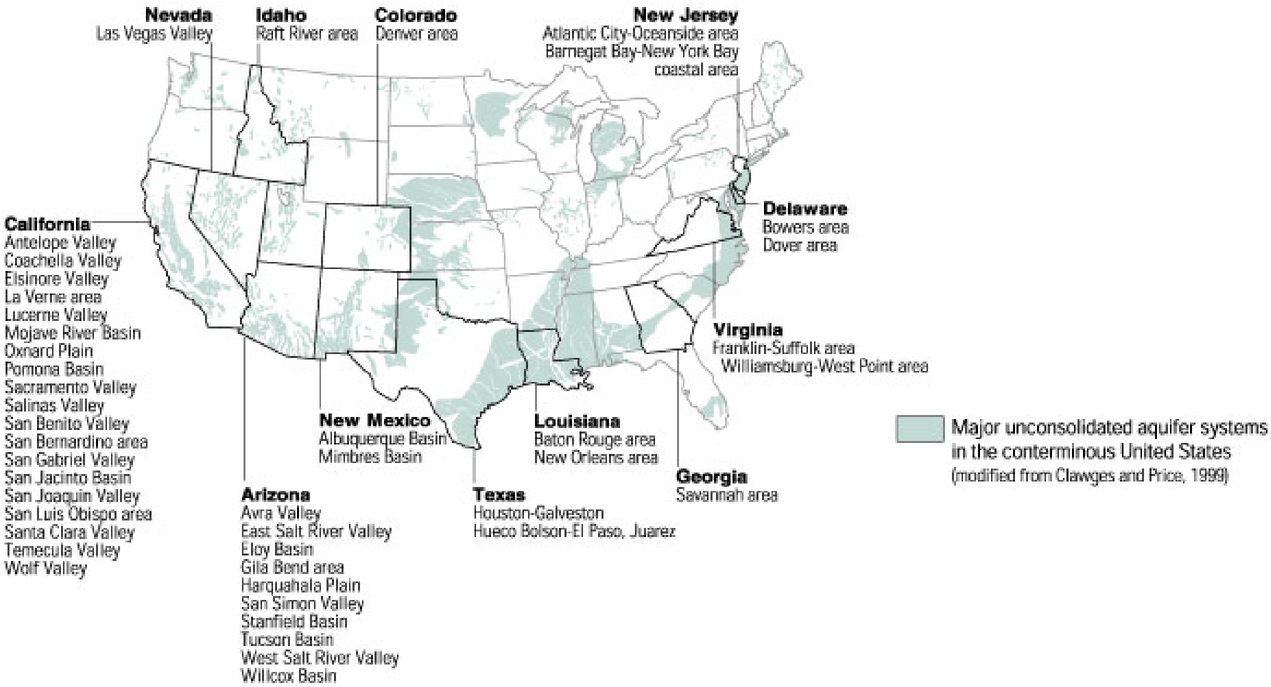


Figure 1. Subsidence is attributed to groundwater pumpage (Galloway et al. 1999).

Regional differences are projected and it is expected that extreme events will precede changes in the mean (Karl et al. 2009). Specifically, in regions where average amounts of precipitation will remain the same, moisture will be delivered in larger storm events. This will reduce the usable amount of water due to the inability of the ground to absorb the water for later release or for recharge of groundwater. Water resources in up to 70 percent of US counties may be at risk due to climate change. More than 1100 counties (one-third of counties in the lower 48) are at high or extreme risk of water shortages by mid-century as the result of global warming (Figure 2). That is, demand for water is expected to outstrip supplies at an accelerated climate-driven rate if no action is taken (Roy et al. 2010).

Energy and water

The Energy/Water nexus is an important issue that has taken on new urgency as concerns have grown about competing demands for this limited resource (WEF 2008). Energy can account for 60 to 80 percent of water transportation and treatment costs and 14 percent of total water utility costs. Much of water resources development took place during the 20th century in an era of both low energy and water prices. Subsidized rural electricity increased agricultural production in irrigated areas and encouraged the use of irrigation in areas without direct access to surface water. Energy-related uses of water include thermoelectric cooling, hydropower, minerals extraction and mining, fuel production (fossil, non-fossil, and biofuels), and emission controls. Energy demands in potable water systems include that required for pumping, transport, treatment, and desalination of water.

Approximately 40 percent of water use in the United States is for energy production, the number two use behind agriculture. This is largely non-consumptive cooling water for power generation plants. The total consumptive use is 3 percent. Trends away from once-through cooling and toward closed-loop cooling reduced the ratio of total water withdrawals to energy produced from 63 gal/kWh (238 m^3/MWh) in 1950 to 23 gal/kWh (87 m^3/MWh) in 2005 (Kenney et al. 2009).

The implementation of renewable energy technologies is a way to meet increasing energy demand and to allay concerns regarding US dependence on imported oil and the climate impacts of burning fossil fuel. Solving one resource problem can affect another if all implications are not considered through systems analyses. Examples of conflicts between renewable energy and water are not difficult to find. Exploiting a fault line beneath the Salton Sea in California to produce 2300 megawatts of geothermal power requires pumping water from the over-allocated Colorado River (IEEE 2010). Production of biofuels from irrigated crops can consume 15 to 30 times more water than it takes to produce a gallon of gasoline (Rogers and Spanger-Siegfried 2010).

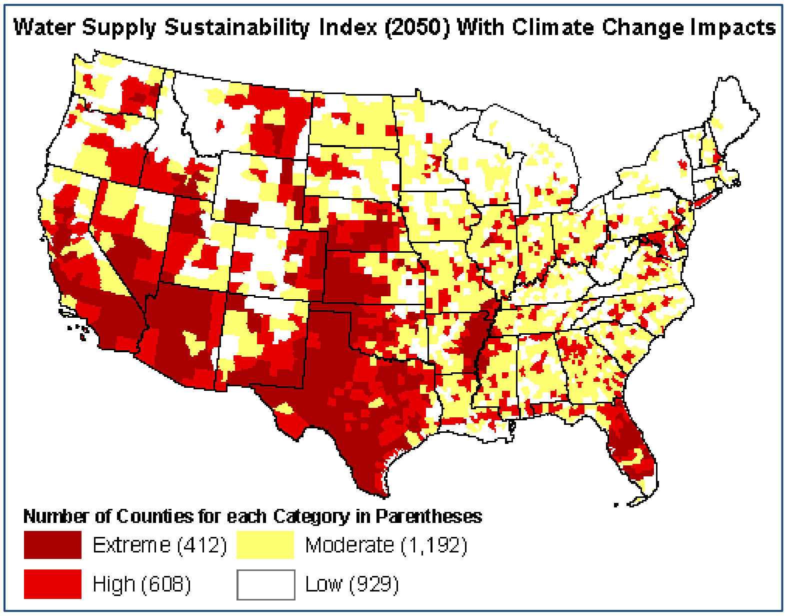


Figure 2. Water supply sustainability index with climate change impacts (Roy et al. 2010).

Cost of water

There is a wide variation in water costs across the United States and these are reflected in Army water rates. Army installations are subject to the local market for water prices. The large backlog of water system upgrades in the United States is starting to be felt through increasing water rates as projects proceed. Water utilities must defend decisions to increase rates to Public Utility Commissions. Army water contracts are supported by the Huntsville Division of the Army Corps of Engineers, which can negotiate and participate in rate interventions if requested. Water cost is a lagging indicator and often does not support quick payback of water efficiency/conservation projects. It can take years to implement projects once rates become high enough to justify the investment.

Although there is not generally a link between the scarcity of water and its cost, water prices are beginning to rise. This is fueled at least in part by the need for infrastructure investments throughout much of the United States. With industrial and agricultural water consumption on the decline since its peak in 1980, system improvements are being largely funded by raising rates for existing customers. Water use has been on the decline for several reasons: loss of industry, increased efficiency in irrigation, decrease in new home construction, migration, and weather (both droughts, which spur conservation; and rains, which reduce the need to irrigate). The rising trend in public supply withdrawals is expected to overcome the decline in other usage sectors. Some believe that energy conservation leads to lower prices that spur increased consumption—the rebound effect—but this has been argued against by energy experts and has only been applied to energy where supply is a factor in determining price (Jenkins et al. 2011, Romm 2011, Lovins 2011).

The American Water Works Association (AWWA) documents a 12.4 percent increase in cost from 2006 to 2008, or 4.8 percent annually. This compares to the consumer price index (CPI) rate of 4.2 percent annually. Of the utilities surveyed, 9 percent decreased their rates, 7 percent maintained their rates, and 84 percent increased their rates between 2006 and 2008. AWWA's average rate was $3.05 per thousand gallons ($0.27/kL) based on the survey of 126 water utilities (AWWA 2009a).

Water quality

Water quality is inextricably connected to water supply. The extent and condition of water can affect human health, ecosystems, and critical environmental processes. Even small changes in quality can render water supplies useless for their intended use, or even hazardous to life. In addition to meeting direct human needs, water provides vital ecosystem services. Among these services are recycling of nutrients, infiltration of stormwater, maintenance of base flow, aquifer recharge, sediment transport, flood mitigation, and maintenance of productive aquatic and riparian habitat. Degrading freshwater resources through pollution or inadequate source protection diminishes the supply of adequate water for environmental or human use.

Sources of water pollution include runoff from urban areas, farmland, and animal feedlots as well as sewage treatment plant discharges. Contamination of surface and groundwater in agricultural and urban areas is characterized by a complex mix of nutrients including nitrogen fertilizer, trace elements, pesticides, VOCs, and their chemical breakdown products. Pollutants include pesticides and fecal matter from farms, chemicals from industrial processes, and fuel and organic compounds from vehicles and transportation routes. Emerging water quality issues of concern include contamination of water with pharmaceuticals and personal care products and water contamination through its use in natural gas extraction by hydraulic fracturing. Other water quality issues include saltwater intrusion from drawdown of aquifers and interactions between surface and groundwater due to overpumping.

Infrastructure condition

There are 240,000 water main breaks per year in the United States. Estimated water loss from distribution systems is 1.7 trillion gal (64 billion m^3) per year at a cost of $2.6 billion per year (USEPA 2007). The American Water Works Association targets 15 percent as a typical figure for unaccounted for water (AWWA 2009b). The American Society of Civil Engineer's' (ASCE's) Infrastructure Report Card gives drinking water a "D-." ASCE further identifies an annual shortfall of at least $11 billion needed to replace facilities at the end of their useful life and to comply with existing and future water regulations (ASCE 2009).

The USEPA's Gap Analysis estimated that, if water system investment remains static, the funding shortfall could exceed $500 billion by 2020, including $263 billion for Drinking Water capital costs (USEPA 2002).

Water system losses also carry a heavy energy burden. Southern California Edison estimates that energy savings in the range of 1,020,125 MWh/year are possible by addressing water system leaks. That amounts to about 26 percent of California's power generated by thermoelectric coal plants in 2008 (Sturm and Lopez 2010).

Water law

Disputed water is becoming all too common in the United States. Over 95 percent of available freshwater resources cross state boundaries and are affected by compacts. Although there are 39 inter-state freshwater compacts, some areas, such as a part of the Mississippi River Basin, do not have compacts in place (Hall and Stunz 2009).

Allocation of water in the United States is determined on the state level and is often based on decisions made during times of plentiful supply and lower demand. These decisions are now considered overly optimistic, especially in light of anticipated climate change. An example of how these historical decisions play out in the 21st century is the Law of the River, a set of collective agreements that divide the rights to the waters of the Colorado River among seven states. The main provisions were established in 1922 and currently allocate more rights than there is water available from the river. The allocations were clarified in 2007 to address concerns related to inadequate supply (US Bureau of Reclamation 2007).

Army installations are entitled to Federal reserved water rights, which hold that when the United States sets aside or reserves public land for uses such as Indian reservations, military reservations, national parks, forests, or monuments, it also implicitly reserves sufficient water to satisfy the purpose for which the reservation was created. These rights exist outside of the state water rights system. However, these Federal reserved rights can be negated through the Endangered Species Act implementation requirements such as those at Fort Huachuca.

In November 1995, the Deputy Assistant Secretary of the Army (Installations and Housing) and Deputy General Counsel (Civil Works and Environment) issued policy guidance for maintaining water rights at Army installations (Johnson and Stockdale 1995). This guidance provides a logical framework for responsible staff elements to track water rights issues. According to the introductory memorandum, the guidance was badly needed because attorneys and engineers at some Federal installations were largely unaware of the importance of maintaining records to protect water rights.

Army Water Overview

Department of the Army (DA) installations used over 158 million m^3 (41.8 billion gal) of potable water at a cost of $67.4M in fiscal year 2010 (FY10) (US Army ACSIM). Water resource availability varies regionally and seasonally, placing some Army installations in positions of water scarcity. Although water scarcity is a critical issue for drier regions, localized droughts are becoming more prevalent and can extend for longer time periods than in the past. By the year 2015, it is estimated that 36 states will face serious water shortages (USGAO 2003). A recent Army study (Jenicek et al. 2009) found that nearly 100 of the 411 installations studied (23 percent) lie within watersheds that are highly vulnerable to water crisis situations.

Water conservation policy

Federal

A number of Federal water efficiency mandates have been promulgated in recent years. Building on the Energy Policy Act of 2005 and Executive Order (EO) 13123, more recent Federal laws and regulations seek to integrate, coordinate, and update prior practices, requirements, and strategies for improving environmental and energy performance. In the area of water management, these laws and regulations require Federal agencies to achieve water reduction targets and improve water efficiency by incorporating best management practices (BMPs) and through the use of water-efficient products and services.

EO 13423 supersedes the requirements of EO 13123 in the development of water management plans and implementation of BMPs for water efficiency as identified by the Federal Energy Management Program (FEMP). EO 13423 requires a 2 percent annual reduction in water consumption intensity (gal/sq ft) from a 2007 baseline through the end of FY15, or 16 percent by the end of FY15. It further requires water audits at Federal facilities of at least 10% of facility square footage at least once every 10 years. Finally, it encourages the procurement and use of water-efficient products and services, specifically identifying the US Environmental Protection Agency's (USEPA's) WaterSense® program as a source of guidance.

The Energy Independence and Security Act of 2007 (EISA 2007) amends Section 543 of the National Energy Conservation Policy Act, the foundation of most current energy requirements. It adds further water conservation requirements and provides guidance for benchmarking. Under EISA 2007, agencies are required to categorize groups of facilities that are managed as an integrated operation and to identify "covered facilities" that constitute at least 75% of the agency's facility energy and water use. Each of these covered facilities will be assigned an energy manager responsible for completing comprehensive energy and water evaluations, implementing efficiency measures, and following up on implementation.

EISA 2007 also addresses post-construction stormwater management for Federal projects, requiring that: "The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5000 sq ft (465 m^2) shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow."

FEMP developed supplemental guidance to help achieve the water goals and to meet the reporting requirements of EO 13423 and the Instructions for Implementing EO 13423. This guidance, Establishing Baseline and Meeting Water Conservation Goals of Executive Order 13423 was developed to assist in the interpretation of, and ultimate compliance with, EO 13423. Specifically, three key elements of compliance were identified and presented: Water Use Intensity Baseline Development, Reduction of Water Use Intensity, and Reporting.

Additionally, BMPs were originally developed by FEMP in response to the requirements set forth in previous EO 13123, which required Federal agencies to reduce water use through cost-effective water efficiency improvements. In response to EO 13423 and to account for recent changes in technology in water use patterns, the USEPA's Water Sense Office updated the original BMPs. The updated BMPs were developed to help agency personnel achieve water conservation goals of EO 13423 and are available at the FEMP web site:
http://www1.eere.energy.gov/femp/program/waterefficiency_bmp.html

EO 13514 expands the water efficiency and conservation requirements of EO 13423 and EISA 2007. This mandate extends EO 13423's 2 percent annual water consumption intensity reduction requirement into FY20, resulting in a total water reduction requirement of 26 percent from the baseline year of 2007. Additionally, the new rules require a 2 percent annual reduction for agency industrial, landscaping, and agricultural water consumption through 2020, for a total of 20 percent water consumption reduction relative to the 2010 base year. EO 13514 also encourages agencies to identify, promote, and implement water reuse strategies that reduce potable water consumption and support objectives identified in the stormwater management guidance issued by the USEPA.

Department of Defense

The Department of Defense Strategic Sustainability Performance Plan (13 Jan 2009) reviews US Department of Defense (DoD) policy and strategy and reviews performance in a number of issue areas including water resources management. The water resources goals include reduction of water intensity in facilities, industrial, and irrigation as stated in EO 13514 as well as the requirement to return development and redevelopment projects to pre-development hydrology, as contained in EISA 2007.

Army policy, regulations, and guidance

The Army's Water Portfolio includes details about the Army Water Vision 2017, DoD and Army water guidance, moving to water security, best management practices and projects, major water programs, and the way ahead. The portfolio is available on the ACSIM web site, at URL:
http://army-energy.hqda.pentagon.mil/programs/water_portfolio.asp

The DA's Sustainable Design and Development Policy Update (Environmental and Energy Performance) (1Oct2010) updates and supersedes the policy of 8 July 2010. The revision includes incorporation of sustainable development and design principles, following guidance as detailed in American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Standard 189.1-2009. All facility construction projects shall achieve a 30 percent reduction in indoor potable water use as compared to a baseline using guidance from ASHRAE. In addition, outdoor potable water consumption shall achieve a reduction of 50 percent from the baseline.

US Army Corps of Engineers Engineering and Construction Bulletins (ECBs) are used to promulgate changes in requirements or processes related to building design and are contained on the Whole Building Design Guide website as part of the Construction Criteria Base, at URL: http://www.wbdg.org/ccb/browse_cat.php?o=31&c=214

The Army's Installation Management Campaign Plan (5Mar2010) contains a number of goals, objectives, and metrics related to water conservation. Additional Army guidance is found in Memorandum DAIM-ZA, Assistant Chief of Staff for Installation Management (ACSIM), 18 March 2003, on the Army adoption of DOE's 10 BMPs for developing water management plans, increasing public awareness, and implementing conservation practices. Many of the policy documents described above are available through the Internet; the *Air Force Water Conservation Handbook* referenced in the memo is available on the ACSIM water policy web site, at URL:
http://army-energy.hqda.pentagon.mil/policies/water_con.asp

Army Regulation (AR) 420-1, effective in February of 2008, calls for water supply and wastewater services to be provided at the lowest Life Cycle Cost (LCC) consistent with installation and mission requirements, efficiency of operation, reliability of service, and environmental considerations. The costs for these services are to be held to a minimum through comprehensive water resource planning, management, and an effective water conservation program—all of which rely heavily upon the adoption of sustainable water technologies. Furthermore, AR 420-1 also requires compliance with the Safe Drinking Water Act (SDWA).

Industry standards and codes

Plumbing and building codes influence the adoption of water efficient products and processes. DoD adopts the International Code Council (ICC) International Plumbing Code (IPC) as the primary standard for DoD facility plumbing systems. The code has a 3-year development cycle for updates. The process of amending codes is long and labor-intensive and requires the support of water stakeholders. Any additions, deletions, and revisions to the IPC are listed in Appendix A "Supplemental Technical Criteria" of Unified Facilities Criteria (UFC) 3-420-01, 25 October 2004.

WaterSense® is a USEPA partnership program that certifies water fixtures that meet rigorous criteria in both performance and efficiency. Specifications and criteria are available for bathroom sink faucets, shower heads, toilets, and urinals. Specifications that are in the public review stage include commercial pre-rinse spray valves and landscape irrigation controls.

The US Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED®) Green Building Rating System is a voluntary standard for high performance sustainable buildings. LEED® certification validates that a building is a high performing, sustainable structure. Certification also benchmarks a building's performance to support ongoing analysis over time to quantify the return on investment of green design, construction, systems, and materials. All Military Construction, Army (MCA) projects meeting the Minimum Program Requirements for LEED® certification are to be planned, designed, and built to be Green Building Certification Institute (GBCI) certified at the

Silver level or higher. WE 1, the Water Efficient Landscaping credit and WE 3, the Water Use Reduction (30 percent reduction) credit are required in all MCA projects.

ASHRAE developed Standard 189.1-2009 in conjunction with the USGBC and the Illuminating Engineering Society (IES). This standard is intended to provide minimum requirements for sustainable or green buildings through the general goals of reducing energy consumption, addressing site sustainability, water efficiency, occupant comfort, environmental impact, materials, and resources. The Army adopted the energy and water standards of ASHRAE 189.1-2009 for all new construction and major renovations through the Sustainable Design and Development Policy.

Metering program

The Army Metering Implementation Plan lays out the methods for determining cost effective metering to include prioritization of installations. This plan assumes $8M per year in Program Objective Memorandum (POM) 08-13 (ACSIM 2006). The metering program also provides advanced metering specifications (US Army ACSIM 2008). Few water meters have been installed in existing buildings to date.

The Energy Policy Act of 2005 requires building level water meters in all covered facilities by 2016. These facilities are defined based on size and/or water use. The meters are automated and will be connected to a central system for remote reading. Presently, it is typical that an installation only meter water at the point of delivery. Reimbursable customers will sometimes have utility meters for billing purposes. When meters are not present, billing is estimated, sometimes inaccurately.

The water efficiency standards found in ASHRAE 189.1-2009 are mandated in the update to Sustainable Design and Development Policy (Environmental and Energy Performance). This update includes requirements for installation of water meters and sub-meters in buildings and systems, though it applies to new construction and major renovation only.

Implications of Army privatization initiatives

The Army has a number of initiatives that seek to privatize functions that were historically executed by civil service employees. In many cases, the move toward privatization was motivated by the deteriorated conditions of the facilities and systems, and by the desire to repair/replace quickly. It is critical that any contracts that affect water consumption on Army installations include provisions for conservation and efficiency.

Utility privatization

On 10 November 1997, the Secretary of Defense, Mr. William S. Cohen, issued a directive to all Military Commanders that utility systems (electric, gas, water and wastewater, and thermal) would be transferred to the private sector. One benefit sought through privatization was modernizing and recapitalizing aging utility systems and bringing them up to current industry standards. Of 355 Continental United States (CONUS) utility systems, 147 have been privatized (including 33 water systems).* Privatized systems are owned by the contractor, who is responsible to provide the utility service including operation, maintenance, and system upgrades. Complications can arise when Directorate of Public Works (DPW) staff desire system modifications in the interest of water conservation. Installations remain responsible for attaining water conservation targets though they may control only a part of the system. Privatization may also be a security risk that limits the flexibility of the installation to plan for and respond to security events.

Maintenance and repair

One large target is contracts for operation and maintenance of utility systems. Standard contracting language should be developed that requires implementation of measures that will safeguard water, e.g., requiring routine leak detection surveys.

Water purchase contracts

Take-or-pay contracts (such as at USA-Grafenwoehr and Fort Drum) should be avoided because they are costly and result in inefficient water use. These types of contracts require a garrison to pay for water even if it does not use all the water called for in the contract.

Residential contracting initiative

Other contracting opportunities include family housing contracts that are part of the Residential Contracting Initiative (RCI) program for Army family housing. RCI contractors in the United States are billed for their water use when the

* 2010 Army Posture Statement, Utilities Privatization.

installation purchases water from an off-site utility company. If the installation is self-supplied and reported water cost reflects only the cost to treat and pump, the RCI contractor is normally not billed (Murrell 2011). Although the contract operator is responsible for operation and maintenance of utilities, the installation is responsible for achieving water reduction targets and ensuring sustainable water supplies. RCI contracts should include water efficiency requirements and should report their progress in support of attaining water use targets.

Army concepts of Net Zero Water

The Army's Net Zero Water Installation Vision states: "A Net Zero Water installation limits the consumption of freshwater resources and returns water back to the same watershed so not to deplete the groundwater and surface water resources of that region in quantity or quality over the course of a year." Using a suite of technologies including aggressive conservation, rainwater harvesting, and water recycling/reuse, buildings can achieve independence from the water "grid."

Definitions and guidance for installations to achieve NZW is provided on the Army Energy Program web site and contained in the Net Zero Water Guidelines:

> *"The net zero water strategy balances water availability and use to ensure sustainable water supply for years to come. This concept is of increasing importance since scarcity of clean potable water is quickly becoming a serious issue in many countries around the world. The continued draw-down of major aquifers results in significant problems for our future. Strategies such as harvesting rain water and recycling discharge water for reuse can reduce the need for municipal water, exported sewage, or storm water. Desalination can be utilized to convert briny, brackish or salt water to fresh water so it is suitable for human consumption or irrigation.*
>
> *To achieve a net zero water installation, efforts begin with conservation followed by efficiency in use and improved integrity of distribution systems. Water is re-purposed by utilizing grey water generated from sources such as showers, sinks, and laundries and by capturing precipitation and storm water runoff for on-site use. Wastewater can be treated and reclaimed for other uses or recharged into groundwater aquifers. Several Army installations are already well down the path to reaching net zero water goals." (US Army ACSIM 2011a)*

Considerations for achieving Net Zero Water

When developing a program for NZW, consideration should be given for varying circumstances between and among Army installations that may affect water supply and demand. For example, hydrologic conditions vary across the United States and include differences in surface and groundwater availability and vulnerability to drought and other climate extremes. Climate conditions will affect the potential applicability of some NZW technologies, e.g., collection of rainwater and condensate. Local laws and codes will also affect technology infusion e.g., the legality of collecting rainwater and the codes regulating graywater reuse. Finally, installations themselves vary in the maturity of water conservation programs; some have already achieved substantial savings and perhaps cannot easily (or cheaply) further reduce consumption.

Hydrologic conditions: Regional watershed assessment

Regional hydrologic conditions vary widely across the United States. Water is available as either surface water or groundwater, shallow or deep. The depth of aquifers fosters replenishment or encourages depletion of fossil water. These and other hydrologic parameters will impact installation water sustainability and the extent to which some installations can achieve NZW.

A national watershed assessment was conducted that evaluated overall watershed health for 2262 HUC8 watersheds.[*] The national map of Army installations was overlaid to show alignment of Army installations with their primary watersheds. Figure 3 shows the national map of watershed health. Individual indicator maps are also available for the 17 indicators related to water supply and 10 indicators related to water demand. Maps are available on the Sustainable Installations Regional Resource Assessment (SIRRA) web site: http://datacenter.leamgroup.com/sirra/.

[*] A hierarchical Hydrologic Unit Code (HUC) consisting of two digits for each level in the hydrologic unit system is used to identify any hydrologic area. The eight-digit cataloging unit is generally referred to as sub-basin.

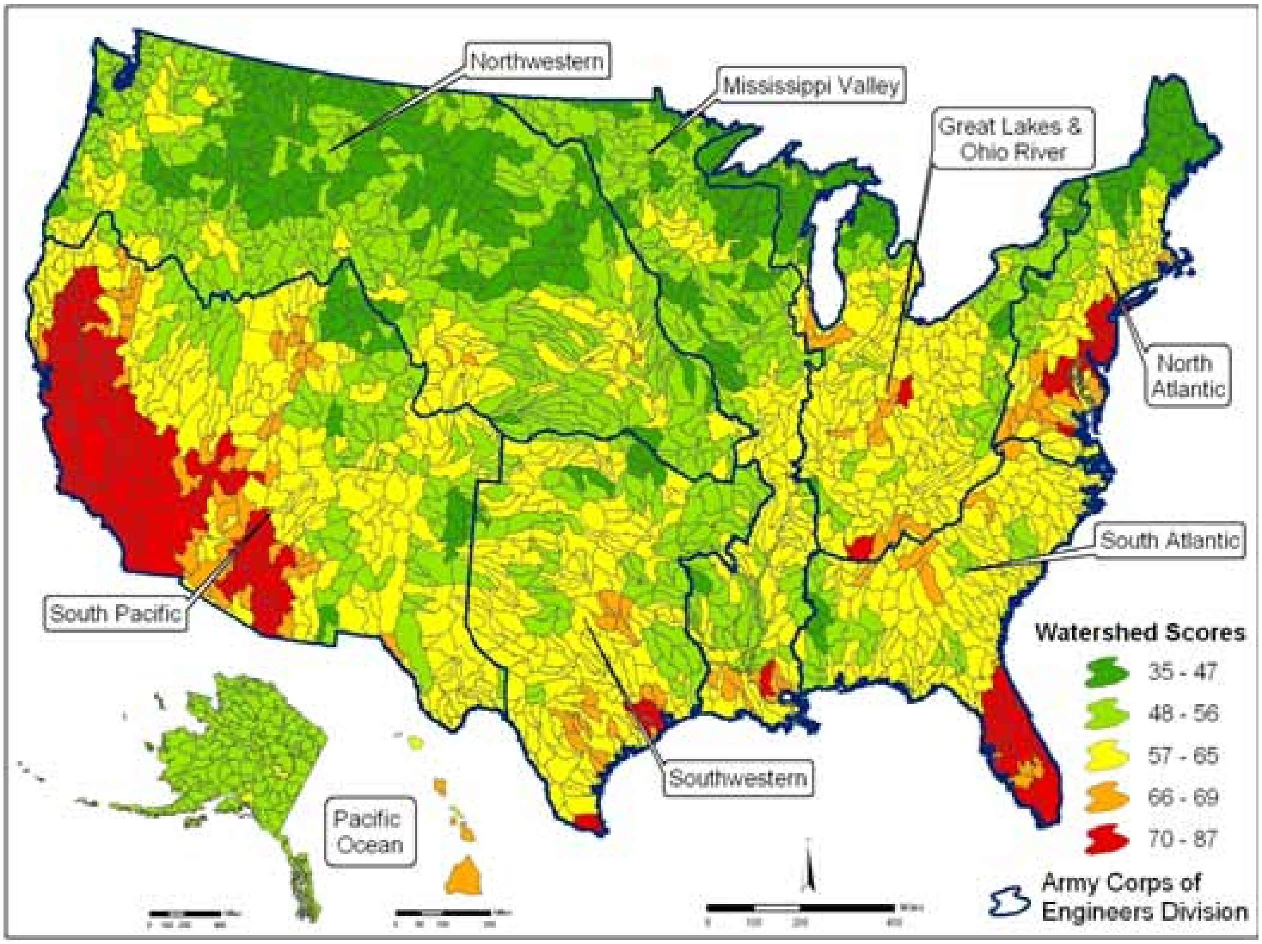


Figure 3. A national map of overall watershed health (Jenicek et al. 2005).

This information could be used to prioritize installations for attainment of NZW. For example, an installation located in a region that is water stressed may be in need of a concentrated water conservation effort that NZW affords. Additionally, an installation located in a region with ample rainfall may have a high probability of success in achieving NZW during the pilot effort.

Climate conditions

As with hydrologic conditions, climate regimes vary geographically across the United States. The National Climatic Data Center identifies nine climatically consistent regions within the United States: Northeast, Central, Southeast, East North Central, South, West North Central, Southwest, Northwest, and West (NCDC 2011).

In addition, energy code climate zones have been mapped. This is an aid to planners and designers when recommending or implementing energy conservation BMPs. This map contains six climate zones based on heating and cooling, and determined by county boundaries (PNNL 2011). A similar mapping could be used to inform adoption of water conservation/efficiency and stormwater BMPs.

Local laws and codes

The ability to implement some water technologies at Army installations varies depending on state and local codes. One example is the reuse of graywater, which is regulated for health reasons. Collection and reuse of rainwater is also restricted in some states due to water rights priorities.

Previous efficiency and conservation efforts

Some installations have already achieved significant water savings through aggressive management over time. Their large savings may already have been achieved and further efficiencies may be difficult as well as cost prohibitive.

Net Zero Water Concepts and Issues

Achieving NZW on the installation level calls for a comprehensive program of policies, programs, and technologies. Realistic and achievable metrics may vary based on region, climate, and, facility and building type. Proposed strategies should be evaluated using a systems approach to minimize unintended consequences that may negate any water savings. One source for ideas to achieve NZW is to learn about what others have undertaken.

Early Net Zero Water efforts

Early efforts at net zero include the Living Machine® at the Adam Joseph Louis Center at Oberlin College, which broke ground in 2000 and is achieving nearly net zero energy and water. NZW is the most difficult condition in the Living Building Challenge.* The Living Building Challenge contains four typologies, one of which is Renovation, which may be appropriate for existing Army facilities. Stanford University has been planning the Green Dorm since 2003. The NZW Project (Philadelphia) encourages households to reduce dependence on water treatment facilities.

Living machine®

Description

Biological wastewater treatment systems date from research during the 1950s at the Max Plank Institute. Many efforts emerged in the 1970s and 80s, with the Living Machine® emerging in the late 90s. Living Machine® is a trademark and a brand name for a biological wastewater treatment process developed by Worrell Water Technologies (Living Machines 2011). The process is composed of tanks, pipes, and filters that mimic the water cleansing functions of a wetland without caustic chemicals, industrial processes, large amounts of biowaste, and high energy costs. Usually located in greenhouses to maintain required temperatures year round, biological elements include aquatic and wetland plants, bacteria, algae, protozoa, plankton, snails, clams, and fish. Systems are designed for a specific capacity of volume water per day in addition to the makeup of the sewage (Todd and Josephson 1996). Living Machines® are present or under construction at such diverse locations as the Port of Portland, OR; the San Francisco Public Utilities Commission; the Marine Corps Recruit Depot, San Diego; and El Monte Sagrado Resort, Taos.

Case study: The Adam Joseph Lewis Center

The Adam Joseph Lewis Center at Oberlin College in Ohio was an early adopter of the concepts of ecological design. The Center includes a Living Machine® that treats 90 percent of the building's sewage, and has a 900-gal (3400 L) rainwater cistern (Figure 4).

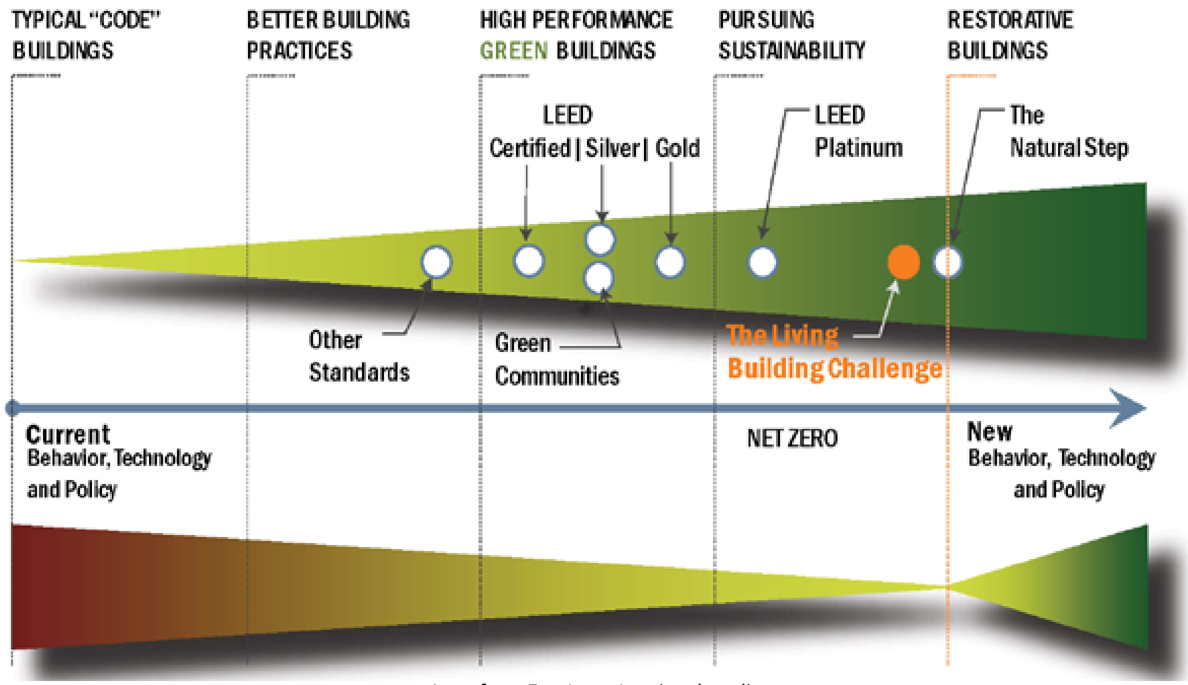
The Lewis Center was opened in 2000 to provide offices and teaching space for Oberlin's Environmental Studies program. This followed a planning period that began in 1992 and included numerous design charrettes and the talents of leading green building and environmental technology professionals. The Center includes a solar energy system (that uses net metering), sustainable materials, building performance monitoring, and biological diversity in what is considered an educational laboratory.

The Living Machine®, designed by Living Technologies, is an ecologically engineered wastewater system that treats wastewater produced by the building's bathroom facilities. It combines elements of conventional wastewater technology with the purification processes of wetland ecosystems and includes microbes, plants, snails, and insects. It is designed to treat up to 2000 gal/day and removes organic wastes, nutrients, and pathogens. The treatment system is contained in a garden-like greenhouse and sends the treated wastewater for use in the building's toilets and for landscape irrigation.

Source: Clear Environmental 2008.

Figure 4. The Adam Joseph Lewis Center Living Machine®.

* Living Building Challenge 2.0, International Living Building Institute, April 2010.



Interface Engineering (undated).

Figure 5. The living building challenge.

The Living Machine comes with an energy cost due to additional mechanical and heating load. A great benefit is derived from the educational value of challenging perceptions of waste versus resource. The treatment greenhouse is clean-smelling and contains lush green tropical foliage year-round. Operating the system (i.e., collecting and analyzing water quality samples, managing plant pests, and monitoring system components) is said to be one of the most popular jobs on campus and the system is a highlight of the building tour (Petersen 2011).

Living Building Challenge

Description

The Living Building Challenge (Figure 5) is a philosophy and certification program of the Cascadia Region Green Building Council and the International Living Building Institute. NZW is comprised of two prerequisites. The first states that *100 percent of occupant's water use must come from captured precipitation or reused water that is appropriately purified without the use of chemicals*. The second states that *100 percent of storm water and building water discharge must be handled on site*. Water independence can be achieved with a combination of water-efficient technologies, rainwater harvesting, municipal reclaimed water system, graywater system, heating/cooling system integration, on-site bioreactor, and behavioral changes (Interface Engineering undated).

Early buildings to achieve Living status include the Omega Center for Sustainable Living in Rhinebeck, NY (2009); the Tyson Living Learning Center in Eureka, MO (2009);[*] and Eco-Sense in Victoria, BC, Canada (2007) (International Living Building Institute 2011).

Case Study: The Solaire, New York City

The Solaire high-rise, located in Battery Park in New York City (NYC), is the first "green," high-rise building in the United States. The Solaire received a LEED Gold rating in 2004, was the first building to receive a New York State Green Building Tax Credit, and contains a "black water" system that purifies all waste water and reuses it for toilet flushing. The NYC water rebate program[†] was initiated after the Solaire team demonstrated a reduction in water use of 43 percent as compared to a typical building (Epstein et al. 2008). This 357 KSF (thousand square feet) 27-story tower houses a membrane bioreactor-based wastewater treatment and recycling system in the basement. It is the first

[*] Indicates year of building occupancy.
[†] The New York City Water Board instituted a rate reduction program for buildings with water treatment systems similar to the Solaire's.

residential treated wastewater reuse application permitted in the United States, beginning operation in January 2004. The 25,000 gal/day (GPD) system recycles and treats the sewage for reuse in toilets, heating, ventilating, and air-conditioning (HVAC) cooling, and subsurface irrigation of an adjacent park. The system is automated with remote alarm and monitoring capability, requiring biweekly operator visits. There is a separate collection system for rainwater used to irrigate the building's green roof. Additional similar water reuse systems were included in subsequent buildings located at Battery Park City (Zavoda 2006).

Net Zero Water program planning

The ability to achieve water independence is challenging at the building level without considering a site, an area, or an entire installation. A NZW strategy should include elements of the most diverse array of policies, technologies, and programs. Any recommended technologies should be evaluated on the basis of maturity, economics (investment cost, return on investment), maintainability, and effect on other systems. An educational component is important to every aspect of water conservation. Even the best technologies can be defeated through improper maintenance or disabled due to lack of information/orientation.

Criteria for a Net Zero Water program

NZW criteria could take a tiered approach, with mandatory provisions and prescriptive provisions that vary for different installations. Some technologies are appropriate for every installation, e.g., plumbing fixtures and appliances. Other technologies apply on a regional basis, e.g., HVAC condensate collection, which is applicable in regions with high levels of relative humidity. Rainwater collection is useful only in regions with adequate rainfall to justify the system. Other technologies are difficult to install in existing buildings yet they could be cost effective and appropriate for new construction.

The criteria for evaluating an installation's success at achieving NZW should be as diverse as the program that will be required for success. A dashboard type scoring could be used with a score/designation for each focus area. Individual focus areas could be scored in detail and then rolled up on the dashboard.

Water intensity

Water intensity is currently measured as kgal/KSF. This definition could be expanded to include a factor that relates to the intensity of use within each building type, e.g., number of people working in an admin building or number of users in a fitness center.

Unaccounted for water

Unaccounted for water could be determined by installing water meters at strategic locations. This metric could be stated in terms of absolute loss or in reduction, or a combination of both. Installations with high rates of loss have the potential to save a lot, but they also might incur high costs doing so.

Landscape irrigation

Landscape irrigation should clearly be minimized, and should use alternate water sources as much as practicable. This metric could be stated in terms of change, with a sliding scale depending on how much is currently being irrigated. Native plantings will support conservation in this area; xeriscaping should be a long-term goal for every installation, maintaining only the turf grass areas that are absolutely necessary.

Alternate water: Rainwater and recycling (graywater, reclaimed)

All sources of alternate water in the region should be considered for this metric. Installations with insufficient sources of water for reuse should not be penalized. The purchase of reclaimed water should be considered a viable source to meet an installation's alternate water supply.

Site water

This metric could encompass the amount of green infrastructure that is used to handle stormwater as compared to conventional stormwater systems. Metrics currently exist for the ratio of pervious to impervious surface. It could also incorporate a measure for problems encountered due to storms e.g., localized flooding.

Water balance

The Army's Net Zero Water concept includes the watershed balance imperative. Although difficult to measure, it is critical that installations strive to return treated water to its original source. Including this requirement ensures that long-term decisions (such as major infrastructure projects) can support the need to preserve water sources. For some installations that use municipal water supplies, the origin of this water may be outside the water shed that the installation is located in. Thus, the installation has no way of returning that water back to the source area.

Command emphasis

The metric for command emphasis should include the key elements of this focus area. Command support, collaboration, awareness, and education will need to be evaluated both qualitatively and quantitatively.

Unintended consequences of reducing water consumption

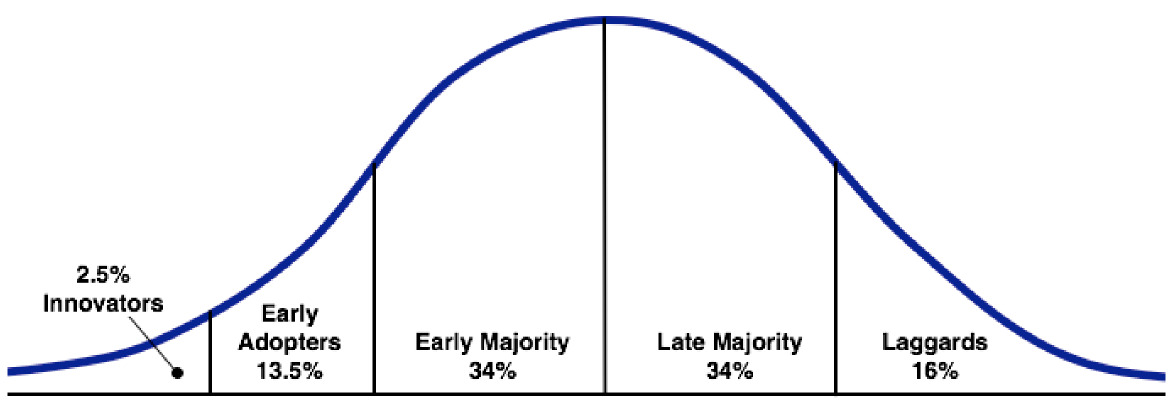
Although water conservation and efficient technologies have been embraced as reports of scarcity accelerate and technologies enter the market place, often these technologies were installed with little thought to potential system-wide effects. Modifying one element in the water system in isolation—water end use devices—can cause unforeseen problems in other parts of the system.

Problems related to reduction of potable water flow include dry drains i.e., drain line transport problems due to insufficient flow (blocked drains and sewage overflows); incorrect chemical dosing for drinking water; water supply pumps operating outside of optimum conditions; potential for standing water in pipes resulting in flushing and/or additional chemicals;* and problems with sewage treatment plant operation due to insufficient water. In Los Angeles, lawn watering restrictions led to an increase in "dramatic pipeline failures known as blowouts" due to cycles of increased and decreased water pressure (Carlson 2010 and Zahniser et al. 2010). On a broader scale, reducing flows from sewage treatment plants can affect aquifer recharge and surface water flows. Some of these issues have been reported anecdotally at Army installations.

Market penetration rates and Roger's innovation diffusion curve

The "diffusion of innovations" theory was first presented by Everett M. Rogers in 1962 and portrays new technologies and practices as following an S-shaped adoption curve. Adopter categorization follows a normal distribution (Figure 6). The first to adopt it are "innovators," followed by "early adopters," and so on (Komor 2004). Rogers' book suggests the standard set of adopter categories that is widely followed today. Adopter distributions follow an S-shaped curve over time and tend to approach normality. One reason is because of the diffusion effect (Rogers 1992, p 269).

Some of the technologies presented in this paper, such as commercial graywater systems, are still in the development phase and near-term adoption of such technology would likely fall within the Innovators category of the curve. Other technologies, such as Ultra-Low Flush Toilets, may fall into the Early Majority portion of the curve. It is often difficult to find market penetration data, however one such study, released by the East Bay Municipal Utility District in San Francisco, CA (Table 1), provides an example of adoption rates of water technologies across various sectors.



Source: Diffusion of Innovations (Rogers 1983)

Figure 6. Adopter categorization on the basis of innovativeness.

* Stale water slowly loses disinfectants like chloramine, potentially allowing bacteria to multiply. As it breaks down, chloramines can also corrode plumbing, allowing more compounds (lead has been documented) to leach into water and to shorten pipe life.

Table 1. Market penetration study of water fixtures by East Bay Municipal Utility District, San Francisco, CA in 2001.

Fixtures/Appliances	Percentage of 2001 Market Share in Each Sector Surveyed					
	Warehouses	Retail	Food Sales	Fast Food	Restaurants	Offices
Ultra low-flow flush toilets	31.8	45.4	47.2	68.0	49.8	
Low-flow urinals	21.6	5.9	24.0	22.2	22.7	24.4
Faucet aerators	72.2	65.9	60.8	60.1	57.5	78.3
Source: EBMUD (2010).						

Ideally, the Army should place itself no earlier than the “early adopters” category to assure that technologies are fully developed and understood before implementation. Placement in the “innovators” category can result in unforeseen consequences because of insufficient time and experience with technologies. However, the Army does have research and development, and technology evaluation assets like the laboratories that often work with technology providers. Technology innovation programs including ACSIM’s Installation Technology Transition Program (ITTP) and DoD’s Environmental Security Technology Certification Program (ESTCP) can support demonstration and validation of technologies in the innovators and early adopters stages, thus reducing the “risks” for Army garrisons. In 2011, ESTCP expanded program investments in energy and water technologies, and this program can potentially provide more opportunities for the Army to test emerging water technologies.

Drain line transport: An issue related to low water flows

Many plumbing experts are concerned that we are at or approaching a “tipping point” where a significant number of sanitary waste systems will be adversely affected by drainline transport problems, especially in larger commercial systems that have long horizontal drain lines to the sewer.

When a graywater reuse system collects discharged water from lavatory basins, clothes washers, bathtubs and shower fixtures for reuse – for flushing water closets or sub-surface irrigation purposes – it is taking water away from the sanitary drainage system. The wastewater flow needs to be maintained at a level to keep the hydraulic depth of flow sufficient for proper water velocities and drain line transport.

Research and codes related to low flows

The Australasian Scientific Review of Reduction of Flows on Plumbing and Drainage Systems (ASFlow) Committee was formed to conduct research into the effects of reduced flows on drainage systems and utility infrastructure. Results of recent research have informed changes to the plumbing code. This research included testing for the impact of reduced flush volumes for toilets and for reduced flow due to non-water urinals (Cumings 2008). Changes to the code were made to address flow challenges of plumbing system components:

1. Non-flushing (waterless) wall-hung urinals (Waterless wall-hung urinals with an integral cartridge seal or integral self-sealing mechanical non-water using urinals -37 mos): A waterless urinal shall be installed only where at least two fixtures, excluding a cleaners sink, are connected upstream of the connection of the waterless urinal to the discharge pipe (AS/NZS 3500.2a).
2. Ninety-degree sweep junctions: Junctions installed in a vertical plane shall not be used for connection of stacks. Sweep and 45 degree junctions may be laid in the vertical plane for the connection of a single discharge pipe or drain provided a 45 degree junction shall only be used for the connection of a water closet pan (AS/NZS 3500.2b) (Clark undated)

The Plumbing Efficiency Research Coalition (PERC) proposed a research study on the drain line carry problem, which will seek to determine the minimum amount of water necessary to safely flush drain lines (Building Design and Construction 2009). PERC is comprised of five organizations: the Alliance for Water Efficiency, the Plumbing Manufacturers Institute, the International Association of Plumbing and Mechanical Officials, the International Code Council, and the Plumbing-Heating-Cooling Contractors Association. The original proposal was estimated at a cost of $1.5 M. Funds were insufficient. PERC has recently developed a low-cost work plan ($170K), with input from ASFlow, and is seeking funding to conduct their research program. PERC is hopeful that their program will receive funding and that work will commence in 2011 (PMI 2010). The USEPA’s *WaterSense*® incentive labeling program is holding off developing a specification for High Efficiency Commercial Toilets pending research in the area of drain-line transport.

AS-Flow and PERC signed a Memorandum of Understanding (MOU) on 3 December 2010. Both groups are working on research programs that seek to investigate the effect of reduced water flows in sanitary drainage systems resulting from reductions in water use from plumbing fixtures and fittings, appliances, and commercial and institutional equipment. The MOU details several areas of collaboration to ensure that research efforts are not duplicated and that information and research results are shared between the two organizations. In addition, the MOU calls for both organizations to interact internationally with standards developing organizations and other researchers for the betterment of global water efficiency efforts (Building Products News 2010).

A recent study by the United Kingdom's Environment Agency recommends that, for new buildings, a revision of existing drainage design standards must be undertaken to accommodate planned reductions in water demand. These alterations could include the use of pipes with smaller diameters and steeper gradients (Henderson 2010). Minimum slope in Australia is 1.67 percent; in the United States, the minimum slope is 1.0104 percent (1/8 in. per foot) because they generally use smaller drain pipes (George 2010)

Recommendations

The Army has few examples of Net Zero Water to draw on in developing its program. Metrics for NZW should be comprehensive in scope yet tailored to the particular circumstances of each installation; some goals will be achievable by all while others are highly dependent on regional factors. In all cases, a systems-based evaluation of potential strategies should be conducted to minimize unintended consequences of low water flows.

It is fundamental that the fixture standards and plumbing codes provide more efficient drainline system performance for effective water savings to be successfully achieved. In new buildings drain sizes can be designed smaller and the minimum slopes can be designed with greater slopes. The Army should consider partnering with code organizations as they embark on efforts to research the effects of low water flow and to develop solutions.

Distribution Systems Strategies

The condition of water distribution systems on Army installations is similar to that of the United States at large in design and pipe age. Improvements in metering and leak detection are necessary to reduce water loss. The cost of unaccounted for water includes wasted energy and treatment chemicals, liability from damage, loss of infrastructure capacity, increased flows to sewer collection systems and wastewater treatment, in addition to wasted water. While standards for technical performance, increased efficiency, and reduced use have been implemented, no such standards exist for leak detection or repair.

Leak detection

A comprehensive assessment of Army installation water distribution systems has not been completed. Recent water sustainability assessments determined that many installations were unaware of unaccounted for water rates. The water loss was estimated at 15 percent, the target established by the American Water Works Association for unaccounted for water (Jenicek 2011). Historic surveys report 9 percent unaccounted for water where it was possible to measure (Bandy and Scholze 1983). It is likely that leakage rates on-post are the same as those for similar-aged systems in local communities, where water loss in excess of 30 percent is reported. Proactive detection through methodical field work is the best solution for reducing water loss. Several methods and technologies are available to detect and control leaks.

Acoustic detection is the most employed and diverse method for detecting leaks. Hydrophones, leak noise loggers, leak noise correlators, streaming cable inline acoustic leak detectors, free-floating inline acoustic leak detectors, acoustic fiber optics, and/or electromagnetic field detection can be used to detect the sounds that pipe leaks make. Thermal detection uses infrared radiation to find temperature differences in the surrounding ground caused by water saturation from leaking water. Electromagnetic systems that have been used to detect buried utilities can also be used to detect leaks. Ground-penetrating radar (GPR) locates subsurface leaks using a rolling unit going back and forth across the pipeline. Finally, the use of chemical tracers relies on the method of introducing a unique gas or liquid to a system. Leaks are detected if the chemical is found outside the system. Tracer gas needs pipelines to be dewatered whereas trace liquids are added to the water. It is recommended that installation staff consult with local drinking water regulatory agencies before implementing liquid tracers (USEPA 2010).

Leak repair

The techniques now available for leak repair help limit, but not eliminate, the need for excavations. Trenchless methods do not require a full excavation of the surrounding soil to fix or stop leaks. The reduction of required manpower and labor at inaccessible jobsites results in lower maintenance costs. The extent of open-trench replacement depends on the amount of pipe deterioration and availability of pipe in stock. Other remedies include wrapping, clamping, and slip-lining. Wrapping is usually limited to pipes 4 in. (10 cm). or less, with rated services up 300 psi (2,068.20 kPa). Wraps are adapted for different environments and pipe materials above and below the ground. Claps are metal collars with gaskets that compress the leakage site on the surface of the pipe. Slip-lining pulls a plastic liner filled with epoxy resin through a previously existing cleaned pipe to seal its leaks (USEPA 2010).

Metering

The lack of building water meters at most Army installations prevents accountability. Most Army installations have no accurate data to assess water loss (Jenicek et al. 2009). The Energy Policy Act of 2005 is being enforced by the Army Metering Program, which will require every Army installation to install advanced water meters at the building level in all covered facilities by 2016 (US Army ACSIM 2008). Propeller, ultrasonic, electromagnetic flow, differential pressure gauges, positive displacement, compound, proportional, and open channel meters are available (USEPA 2010). Meter reading can be done manually or automatically. If a comprehensive building level metering system is constrained by cost, then strategies that identify critical locations at an installation should be employed. Critical meters should be installed where usage is most extreme, critical, and where conservation and leak repair may have the most benefit to the entire system.

Recommendations

Elimination of water waste through an aggressive leak detection and repair program is a key component of a NZW program. System monitoring and repair must start with a plan that prioritizes high risk and critical survey zones while establishing a survey routine that encompasses the entire system. This should include routine checks of older or higher risk pipes. Comprehensive leak detection must be done with a combination of detection technologies intended to reduce survey time and address the comprehensive inventory of pipe systems. Similarly, selection of pipe repair technique will be based on location and pipe status. Water meters can be installed strategically to provide the most information on system condition while helping detect and assess water loss. The keys to water distribution system monitoring and maintenance are to be vigilant and to take proactive measures.

Power Plants, District Plants, HVAC Systems and Equipment

Power plants, district plants, HVAC systems, and other utility equipment account for a significant percent of water loss on an installation. Criteria for new buildings and major renovations include water-efficient technologies. A large impact in water loss prevention can be made through adopting a comprehensive and rigorous inspection and maintenance program. The following summarizes best management practices that help attain NZW in power plants, district plants, HVAC systems, and equipment.

New water technologies that are required in new construction and major renovation should be considered for all existing buildings. These include retrofitting or replacing single pass cooling systems, evaporative coolers, and humidifiers; collecting condensate from air handling units for reuse; installing condensate receivers with pump plus piping back to condensate return lines for all condensate draining to waste water systems; and equipping cooling towers and evaporative coolers with makeup and blowdown meters, conductivity controllers, overflow alarms, and efficient drift eliminators. Best management practices for maintenance and repair include:

- Monitor and repair water distribution system leaks.
- Establish a steam trap inspection and replacement program.
- Establish a boiler inspection program, including deaerator, to include piping connections, malfunctions, and neglected maintenance. Optimize the de-aerator vent rate. Insulate the deaerator section and storage tank and all hot water and steam piping to avoid water and heat losses from condensation.
- Implement a water treatment program for boiler water systems.

Recommendations

It is recommended that installations adopt a comprehensive and rigorous inspection and maintenance program for power plants, district plants, HVAC systems, and equipment. Graywater and condensate should be used, to the extent practicable and legal, for cooling towers and any remaining once-through cooling. Any replacements and upgrades should adhere to the water conservation requirements contained in the Whole Building Design Guidelines.

Treatment Plants

Central treatment plants offer opportunities to support NZW on Army installations. Advanced water treatment systems can enable the use of water that is otherwise unfit for consumption, for example, brackish or saline water. Wastewater treatment plants provide the opportunity to reclaim tertiary treated effluent for reuse for irrigation and other non-potable uses. The use of decentralized wastewater treatment treats wastewater near to where it is generated, reducing the need for extensive infrastructure.

Drinking water treatment

The primary role of drinking water treatment in NZW is the potential for emerging technologies to bring otherwise undrinkable water up to drinking water standards. Water purification removes unwanted solids, chemicals, and biological contaminants from source water for human consumption and other uses. Out of 84 water treatment plants documented on Army installations in 2008, 21 were privatized, 39 were exempted, two were in process, and 12 were to be evaluated (IMCOM 2008).

Centralized water treatment plants work by extracting water from a source, treating in a centralized plant, and pumping water to all system customers at a range of distances from the plant. Typical steps in the purification process include pre-treatment (screening, storage, pre-conditioning, and pre-chlorination), pH adjustment, flocculation, sedimentation, filtration (rapid sand, membrane, slow sand), and disinfection (chlorine, chlorine dioxide, chloramines, ozone, ultraviolet).

Point-of-Use/Point-of-Entry water treatment systems are a type of decentralized system. These water treatment methods are intended for use at the point of consumption. These are appropriate for a small scale such as a small community or household level. They can be useful where safely storing water is a challenge. These systems are most often used in underdeveloped regions due to infrastructure constraints and in developed regions as a supplement to water treatment or to safeguard against particular contaminants of concern. Components of a point-of-use system include boiling, ceramic pot filtration, chlorination, cloth filtration, natural or chemical coagulation, pasteurization, sand filtration, and/or solar disinfection.

Other water treatment systems include membrane filtration, ultrafiltration, and reverse osmosis. Microfiltration (pore size of 0.01 micron) removes many microorganisms, but viruses remain. Ultrafiltration (pore size of 0.01 micron) removes some viruses, but no dissolved substances. Nanofiltration (pore size of 0.001 micron) removes most organic molecules, nearly all viruses, most of the natural organic matter, and a range of salts. Reverse Osmosis (pore size of 0.0001 micron) produces essentially pure water, including removal of minerals (SDWF 2011).

ERDC-CERL partnered with the Strategic Environmental Research and Development Program (SERDP), the Army Research Office, the Army Environmental Policy Institute, and the WaterCAMPWS in sponsoring a workshop, “Military Applications for Emerging Water Use Technologies.” The workshop served as a platform for government, academia, and trade associations to share information; to increase visibility of current efforts; to explore the potential of existing, emerging, and future technologies and other options for military installations; and to identify potential thrust areas where demonstrations and future research could be focused. The report contains a number of recommendations for both forward operating and fixed facilities (Scholze et al. 2009).

Wastewater treatment

The primary role of wastewater treatment in NZW is the potential use of treated wastewater as an alternate water source. Treating and reusing wastewater is becoming an acceptable solution to water scarcity. Sewage treatment is required to meet the Clean Water Act of 1972, which requires municipal wastewater treatment plants to meet secondary treatment level. Secondary treatment level requires the removal of dissolved and suspended biological matter, typically done with micro-organisms or aeration stations. Out of 84 sewage treatment plants documented on Army installations in 2008, 31 were privatized, 40 were exempted, one was in process, and 12 were to be evaluated (IMCOM 2008).

Centralized wastewater treatment plants work by collecting sewage through a conveyance system from a range of sources including residential, commercial, and industrial, and then treating it in a centralized plant. The objective is to produce environmentally-safe treated effluent/treated sludge suitable for disposal or reuse. In combined systems, sewage may include stormwater runoff.

Typical steps in the treatment process include pretreatment (screening, grit removal, fat and grease removal), primary treatment (sedimentation), secondary treatment (aerobic biological processes), sludge digestion, and sludge drying and finishing. Other treatment components may include activated sludge plants and surface-aerated basins.

Constructed wetlands are intended to mimic natural wetlands. These systems provide a high degree of biological improvement and can act as primary, secondary, and sometimes tertiary treatment. Alternatives include surface flow or subsurface flow, and horizontal or vertical flow. The systems are robust with treatment capacity improving with time unlike conventional treatment plants. Space limitation may be an obstacle to widespread adoption. A demonstration project is currently underway at Marine Corps Recruit Depot San Diego as part of the ESTCP program (Tertiary Treatment and Recycling of Waste Water, ER-201020). This project is demonstrating the Living Machine® system documented earlier in this paper (ESTCP 2011).

Reclaimed water is effluent generated by a wastewater treatment plant that is treated to a level appropriate for reuse. Allowable uses vary by state; state departments in charge of regulating water reuse are contained in the USEPA's *Guidelines for Water Reuse*. For installations that do not treat wastewater on site, purchasing reclaimed water from a local source may be the more practical choice. Reclaimed water is generally lower in cost than potable water purchased from a utility. Installations with sewage treatment plants, whether contractor or Army-operated, may generate their own reclaimed water. The Federal Energy Management Program provides guidance for using reclaimed water (FEMP 2010).

Decentralized systems are sometimes an option to eliminate septic systems (on-site systems) or an alternative to a centralized system, which may be more costly. Decentralized treatment to complement or replace central plants can provide the added benefit of reducing energy consumption of these processes. Cluster systems serve two or more dwellings and less than an entire community. One example of such a system uses watertight effluent collection pipes, sand-gravel filter treatment, and effluent disposal by subsurface drip irrigation. Decentralized systems may be cost effective and enable better watershed management by keeping water within the watershed that it was withdrawn from.

Recommendations

Advanced drinking water treatment systems can purify otherwise undrinkable water thereby increasing available water. This is sometimes at the cost of higher energy consumption.

Wastewater treatment has the potential to serve as a primary source for alternate water on the installation. Tertiary treated wastewater can be used on-site for irrigation, dust suppression, toilet flushing, and cooling tower make-up. In addition, this water can be used to replenish local groundwater sources. Installations should follow FEMP's recommended process to help determine whether purchased or on-site reclaimed water is appropriate. Likewise, decentralized wastewater treatment as an option for providing a local source of reclaimed water and reducing energy usage will require detailed studies.

Alternate Water Sources

Alternate water sources are a major factor in attaining NZW. Atmospheric water is available as rain or stormwater, condensate capture, and water from air. Graywater is derived from sinks, showers, and clothes washers and can be collected locally or obtained as reclaimed or recycled water from a centralized treatment plant. Factors that affect the applicability and success of alternate water sources include technology, regulations, and maintenance. Public acceptance of reused water must be addressed through education.

Atmospheric water

Naturally occurring water in the form of rainwater, stormwater, and condensate from water vapor are all available for non-potable use. Rainwater is typically collected from roof runoff into gutters and stored in rain barrels and cisterns.

Stormwater is collected from storm drains and therefore tends to gather more debris and is exposed to different pollutants than rainwater. Consequently, stormwater is more likely to need treatment before use (Hoffman 2008). Condensate water is water that condenses on a surface that holds a temperature below dew point. Water vapor is regularly collected in air-conditioning and refrigeration units that operate in warm, moist places. Condensate water is generally clean enough to be put to either of these uses without treatment. (Hoffman 2008 and Chesnutt 2007). The capacity to collect water is regionally dependent and laws that govern collection are state dependent (Johnson 2009).

Rainwater harvesting

Harvested water is generally clean and therefore has many applications. This may include cooling tower make-up supply, which otherwise has an increasing salinity problem. The high level of purity also enables longer storage times before use. Harvesting technology selection is dependent on climate and building type.

Rainwater can pick up roof debris and organic material en route that needs to be filtered before entering storage. Bacteria levels in untreated rainwater should be tested routinely. Additional treatment of rainwater, using ultraviolet (UV) radiation or ozone, for example, can usually achieve levels of water quality high enough to be potable (Texas Commission on Environmental Quality 2007).

Rainwater harvesting components usually include a catchment surface, gutters and downspouts, leaf screens, first-flush diverters, filters, storage tanks, pumps, and disinfection equipment. The size of catchment and storage containers are typically dependent on climate and demand. Designs may be for above or below ground. Factors such as outside temperature ranges, soil, available space, and budget usually determine what type of tank should be used. Tank materials may include fiberglass, polypropylene, galvanized metal, or concrete (Texas Water Development Board 2005).

Condensate collection

Condensate capture and reuse technologies are applicable across Army installations based on the local climate and the building type and usage patterns. Cooling towers are often located in proximity to air handling units (AHUs), drawing on potable water supplies for make-up water required to replace water lost to evaporation. Connecting these water producing and water using components within the same building system will preserve potable water for required uses, reduce energy required to process and pump potable water, reduce cost for purchased water and condensate disposal, and support sustainable water supplies for the future.

The availability of adequate amounts of condensate for collection depends upon ambient humidity and the number of hours per year of mechanical cooling required. The Southeastern United States is an obvious locale for effective condensate collection (Figure 7). Other marginal areas will depend on building occupancy, type, and outdoor air requirements (Lawrence and Perry 2010).

Atmospheric water generator

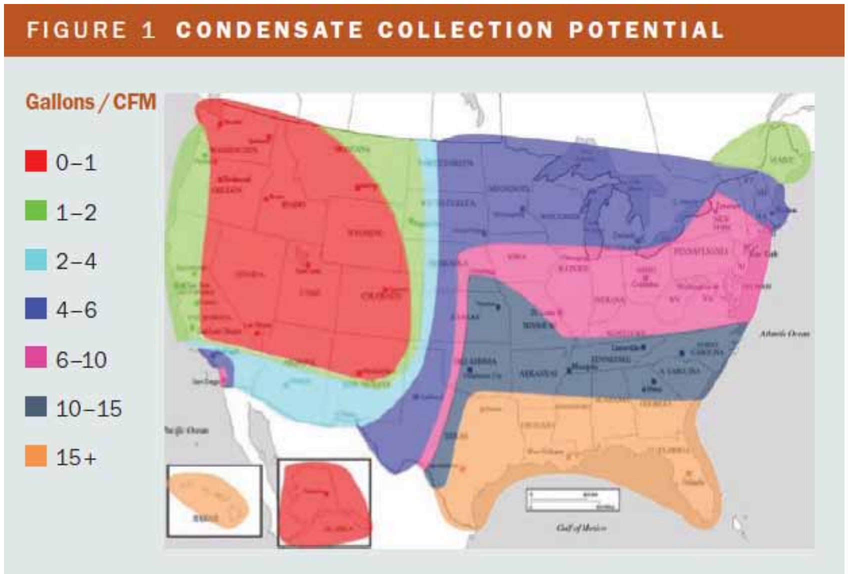
Condensate collection may be accomplished using an atmospheric water generator. Water may be extracted from humid ambient air by cooling or with the use of desiccants. Historical methods include air wells in Middle Eastern deserts 2000 years ago and water-collecting fog fences.

Cooling condensation systems operate similar to dehumidifiers. Ambient air is circulated across a coil containing refrigerant. Condensate is collected, filtered, and treated to remove mold, bacteria, algae, and other organisms before being used. Cooling condensate systems do not work efficiently at temperatures below 18.3 °C (65° F) or relative humidity below 30 percent.

Wet desiccant water generators use salt in a concentrated brine solution to absorb ambient humidity. The use of energy from solar collectors to heat the brine and release salt-free evaporate makes this application well suited for arid and semi-arid areas where more water evaporates than precipitation falls (ScienceDaily 2010).

Graywater reuse

Graywater is wash water, or water discharged from lavatories, showers, bathtubs, clothes washers, and laundry trays. Graywater reuse is a term describing the reclamation, treatment, and recycling of these waters. While irrigation and toilet flushing are two of the most common reuses of water, a variety of other possibilities exist, including groundwater/aquifer recharge, heating/cooling (cooling towers, water-cooled equipment, and boilers), vehicle washing, and some industrial processes. Recycled and reclaimed water must meet quality standards that ensure protection of health and user acceptance (Duffy 2009).



Source: Lawrence and Perry (2010).

Figure 7. Map of condensate collection potential.

Packaged systems

Packaged graywater treatment systems are "off the shelf" and ready for installation. They are widely applicable and not project-specific. Systems are generally simple, consisting of a three-way diverter valve, a treatment assembly such as a sand filter, a holding tank, a bilge pump, and irrigation or leaching system. Building-scale systems are in use overseas and not widely implemented in the United States, but are receiving considerable attention from organizations such as the International Water Association (IWA).

A simpler form of graywater reuse can be implemented in washrooms. The water from the lavatory can be collected under the sink and transported to the flush fixture's tank to be used for flushing. Such a technique could be retrofitted to existing bathrooms.

Regulation

Graywater reuse is generally regulated at the state level. This in turn is reflected in building plumbing codes. In addition, counties often have specific health related requirements. The greatest potential regulatory risk for graywater reuse in general is use in states that do not allow graywater reuse. Army installations planning to use graywater at the building level should work closely with local authorities to establish a standard for processes and/or water quality.

The International Plumbing Code, the USEPA, and ASHRAE have established some requirements for graywater systems, e.g., purple piping for visibility and back-flow controls to prevent cross contamination. Other code provisions may include requirements that govern required treatment level; material, type and location of locking valves; marking; separation/barriers; and signage. Regulatory Framework Title 22 (California) requires inspection by an AWWA cross-connection control program specialist before initial operation and annually thereafter.

Industry standards

Two main consensus standards for graywater treatment systems are currently under development. The first is the NSF350, "On Site Residential and Commercial Water Reuse Treatment Systems." This standard will cover systems up to 1500 gpd treatment capacity for restricted and unrestricted potable use. This standard will require a 26-week testing period. Release of the standard is expected by mid-2011. Products certified to this standard will emerge in mid to late 2011 (Martin 2010).

The second standard is the Canadian Standards Association (CSA) B128.3, "Performance of Non-Potable Water Treatment Systems." This standard will cover systems to approximately 2650 gpd treatment capacity that can be connected to multiple water sources. This standard will require a 46-week testing period. Release of the standard is expected by late summer 2011 (Martin 2010).

Graywater reuse challenges

The biggest challenges facing gray water are regulatory, though severe droughts have helped to ease those restrictions in some regions. States that have statewide regulations permitting gray water use include Arizona, California, Montana, Nevada, New Mexico, Oregon, Texas, and Utah. This list is anticipated to increase as concerns about water scarcity continue to grow.

Public acceptance is a challenge for the reuse of graywater within buildings. The most common concern is the potential threat to human health. However, demands on operation and maintenance, behavior change education of users, and water aesthetics can also be strong determinants of user acceptance.

A final barrier to the widespread adoption of gray water reuse is the economic challenge of modifying existing infrastructure to facilitate the practice. For example, reuse of gray water for flushing toilets is a sensible idea. However, in most buildings, water and wastewater lines extend throughout a complex network of pipes and other utilities that are often not easily accessible for modification. Even if reusable fractions of a building's wastewater were intercepted and centrally treated by a pressurized membrane filtration process, the resulting gray water would still need to be delivered to toilets by pumping through new, independent lines. The associated costs and infrastructure modification make this approach a challenge in many cases. There is a need for more practical, streamlined approaches for reusing gray water.

Recommendations

The three factors that present challenges in the near future with implementing graywater reuse are technology, regulatory, and maintenance. Technology consensus standards are still under development meaning that systems now on the market have not met the rigorous testing that such standards impose. Additionally, technological immaturity and limited market penetration result in relatively high first costs. Differing code requirements require that these technologies must be evaluated on a case-by-case basis unique to the locale. Rigorous maintenance is imperative to ensure that health and safety are not compromised. This obstacle can be overcome through the use of maintenance contracts.

Decentralized, building-level graywater reuse poses challenges. An installation must be aware of the economic considerations, installation, management, oversight, monitoring, and maintenance needed to maintain these systems and prevent cross contamination.

Efficient Appliances and Fixtures

Water efficient appliances and fixtures are some of the easiest conservation retrofits to accomplish. EPAct 2005, EISA 2007, EO 13423, and EO 13514 require Federal agencies to achieve water reduction targets and improve water efficiency by incorporating BMPs and through the use of water-efficient products and services.

In addition, the Army now mandates that indoor water consumption in new construction and major renovation shall use technologies that result in at least 30 percent reduced consumption of potable water as compared to the base case facility. Standards have been established for specific technologies by USEPA *WaterSense*®, ENERGY STAR, and ASHRAE 189.1-2009. Army guidance for new construction can be found in the Whole Building Design Guide.

While criteria specifies a maximum flow, a range of flows are available for some fixtures and appliances. It is important to ensure that user needs are met while achieving the greatest savings possible. *WaterSense*® labeled devices have been tested for efficacy as well as efficiency, that is, shower heads deliver an adequate flow and toilets pass flush criteria with testing medium. Some super-saver appliances may be well worth the investment to decrease water use even more.

Plumbing fixtures

The largest water users in the residential sector are toilets, accounting for nearly 30 percent of indoor water consumption. Savings are achieved by reducing the number of gallons per flush (gpf) volumes. ASHRAE 189.1-2009 mandates that tank-type toilets shall be 1.28 gal (4.8 L) and shall be certified to the performance criteria of the USEPA *WaterSense*® Tank-Type High-Efficiency Toilet Specification. In addition, urinals in Army facilities will comply with ASHRAE 189.1-2009 as specified in the Sustainable Design and Development Policy Update (ACSIM 2011b).

ASHRAE 189.1-2009 also sets forth maximum flow rates for flow fixtures. Public lavatory faucets shall not exceed 0.5 gpm (1.9 L/min); public metering self-closing faucets, 0.25 gal (1.0 L) per metering cycle; residential bathroom lavatory sink-faucets, 1.5 gpm (5.7 L/min) or 60 psi; residential kitchen faucets, 2.2 gpm (8.3 L/min); residential showerheads, 2.0 gpm (7.6 L/min) or 80 psi.

Appliances

ASHRAE 189.1-2009 mandates that residential clothes washers shall comply with the ENERGY STAR Program Requirements for Clothes Washers, achieving a maximum water factor of 6.0 gal/cu ft (800 L/m^3) of drum capacity;[*] however, the most efficient washers use 3.1 gal/cu ft (467 L/m^3). Furthermore, if clothes washers are operated only when full on low-water, short cycles, additional water savings can be realized. Clothes washers installed in publicly-accessible spaces (e.g., multifamily and hotel common areas) and coin- and card-operated clothes washers of any size used in Laundromats shall have a maximum Water Factor of 7.5 gal/cu ft (1.0 kL/m^3) of drum capacity-normal cycle.

ASHRAE 189.1-2009 mandates that residential dishwashers shall comply with the ENERGY STAR program requirements for dishwashers, achieving a maximum water factor of 5.8 gal (22 L)/full operating cycle. This maximum will be lowered on 1 July 2011.

Commercial food service

When dishes must be pre-rinsed, water savings can be realized through low-flow spray valves that use no more than 1.25 gpm at 60 psi. Additionally, eliminating scraping troughs, or using troughs that recycle water, will result in water savings. Replacing food waste disposers with food waste strainers or eliminating them altogether can result in water savings as well. Training workers to scrape dishes instead of pre-rinsing them before putting them in the dishwasher will help commercial kitchens conserve water. When possible, composting is always considered an environmentally preferable option.

The *WaterSense*® program is currently developing specifications for pre-rinse spray valves. Once developed, *WaterSense*® pre-rinse spray valves should be sourced when switching to this technology. *WaterSense*® collected data on use of PRSVs from January through June 2010; the results can be found on the *WaterSense*® web site.

High-efficiency dishwashers

Inefficient or conventional appliances should be replaced with ENERGY STAR qualified models that have significantly lower gallons per rack and energy consumption rates. Commercial dishwashers must use 1.00/0.95/0.70/0.54 gal of water per dish rack depending on whether they are (respectively) under-counter/stationary single tank door/single tank conveyor/multiple tank conveyor-type dishwashers.

High-efficiency ice machines

Choose air-cooled ENERGY STAR /CEE[†] Tier II ice machines or ultra efficient California Investor Owned Utilities (CAIOU) rebate-qualified/CEE TIER III models with higher production capacity. Higher-capacity machines tend to be more efficient in their ice production, measured in kWh/lbs of ice.

High-efficiency steam cookers

Choose ENERGY STAR and CAIOU rebate-qualified steam cookers that have significantly higher cooking efficiencies. Boilerless (connectionless) steam cookers tend to have lower production capacities than steam generator and boiler-based models, and are best suited to batch-cooking. Where possible, analyze production needs and replace boiler based steamers that can use up to 40 gal/h and have cooking efficiencies below 30 percent with boilerless steamers that use little water (< 5 gal/h) and cooking efficiencies up to 85 percent.

Industrial laundry operations

Install tunnel washers for continuous basis operations. Install warm water recycling systems. Install controllers for water softeners to adjust for volume of water treated. Use only when needed; do not recharge based on timer (FEMP BMP [Best Management Practice] # 13).

Laboratory and medical equipment

Steam sterilizers and autoclaves are used for sterilization in medical and laboratory settings. While only steam sterilizers use water as the medium for sterilization, both machines use water for other parts of the sterilization process. Replacing or retrofitting older sterilizers and autoclaves —so that the models do not keep water flowing when in standby mode and so they recirculate rather than dispose of cooling water— will help facilities conserve water. Addi-

[*] Water factor is defined as gallons of water per cycle per cubic foot of washing space.
[†] Consortium for Energy Efficiency (CEE).

tionally, using the smallest possible model for the instruments being sterilized and sanitizing only full loads can save even more water.

Recommendations

Replacing fixtures and appliances wherever possible is a guaranteed route to water savings. In particular, devices that use hot water will show a quicker payback due to energy savings. There are several tools available on line to calculate the savings in water, energy, and cost due to retrofits or replacements. These calculations using installation-specific data will provide the most accurate assessment and help installation staff to prioritize upgrades.

Landscape Irrigation

Irrigation is often the largest single source demand on any installation. The largest cost and resource savings will likely come from substituting alternate water sources for potable water for landscapes that must be irrigated (Vickers 2001).

Guidance

Standards for irrigation of new planted areas are found in ASHRAE 189.1-2009. Outdoor water consumption shall be 50 percent as compared to the base case landscaping employing conventional means. Guidance is contained in ASHRAE 189.1-2009 Sec. 6, and in the 1994 Presidential Memorandum "Environmentally and Economically Beneficial Practices on Federal Landscaped Grounds."

ASHRAE 189.1-2009 also requires hydrozoning of automatic irrigation systems to water different plant materials such as turf grass versus shrubs. Landscaping sprinklers shall not be permitted to spray water directly on a building or within 3 ft (1 m) of a building.

Irrigation systems for new sites must be controlled by either: (1) a qualifying smart controller that uses evapotranspiration (ET) and weather data to adjust irrigation schedules and that complies with the minimum requirements, or (2) an on-site rain or moisture sensor that automatically shuts the system off after a predetermined amount of rainfall or sensed moisture in the soil. Qualifying smart controllers shall meet the minimum requirements of the Smart Water Application Technologies (SWAT) Climatological Based Controllers 8th Draft Testing Protocol.

Exceptions allowing a temporary irrigation system used exclusively to establish new landscape shall be exempt from this requirement. Temporary irrigation systems shall be removed or permanently disabled at such time as the landscape establishment period has expired.

Irrigation controls

Both turf and non-turf irrigation systems can conserve water by using Smart irrigation controllers. These units estimate or measure depletion of available plant moisture to control an irrigation system. Controllers use input either from soil moisture sensors or from evapotranspiration, rainfall, and solar radiation. Smart controllers require adjustment once they are installed.

The *WaterSense*® program is currently developing specifications for weather- and sensor-based smart controllers. Once developed, *WaterSense*® smart controllers should be sourced when switching to this technology. *WaterSense*® specifications for weather-based irrigation controllers are in draft. Specifications were based on the Irrigation Association's standards. The *WaterSense*® program also certifies a variety of irrigation professionals.

Recommendations

Reducing or eliminating landscape irrigation is a quick and relatively simple solution to a major water demand on installations. Installations may choose to use rainwater, graywater, condensate, or reclaimed water to irrigate gardens or landscaping. Smart irrigation controls can be used to provide adequate amounts of water to sustain vegetation at the optimum time of day. For new areas or those under renovation, planting native species will limit water requirements beyond that required to establish plantings.

Low Impact Development

NZW supports the EISA 2007 requirement to restore development or redevelopment sites to pre-development hydrology. Low Impact Development (LID) is an approach that uses natural landscape features to manage stormwater as close to the source as possible. Conventional approaches to stormwater control typically collect runoff in large facilities at the base of drainage areas. Hard surfaces (such as curbs, gutters, and piping) increase the speed and volume of runoff, which can result in serious erosion problems.

The new principles of LID focus on controlling abstractions at the source with micro-scale controls scattered throughout the site. LID aims to reduce the effects of development and preserve the land's natural features via infiltration, storage, and reuse, and evapotranspiration techniques (USEPA 2005). LID techniques include bioretention facilities, rain gardens, vegetated rooftops, rain barrels or cisterns, and permeable pavements. LID techniques can be used for new land development, redevelopment, or retrofits of existing infrastructure.

Army installations typically use traditional stormwater management techniques using hard infrastructure. Now master planners and project delivery teams are being asked to use LID principles to minimize stormwater problems at the site. Acceptance of the new ideas will take a strategic effort on the part of the master planners, installation environmental and stormwater personnel, and the Army Corps of Engineers project delivery teams and the contractors who support them.

Current installation design guides (IDGs) pose problems for several areas of sustainable design and progress towards net zero goals. Existing standards may impede or prevent application of LID principles; flexibility would facilitate sustainable design and development efforts that meet Army sustainability and energy mandates. These conflict areas include roof forms, installation planting lists, and stormwater management.

A bigger issue for successfully meeting the EISA requirement is the definition of the "Site" boundaries. Note that the LEED® project boundaries must be consistent throughout all project documentation, but the EISA stormwater site could be different. The size of the site and the soil characteristics are two key factors in determining the difficulty of meeting EISA requirements. The site could be considered the entire installation, a watershed or area within an installation, visual themes and zones defined in the IDG, or the planned construction site for a building or cluster of buildings.

Despite the challenge and high expense of stormwater management on small sites where a building and parking lot will be constructed, installation customers often require this of design teams. It is more practical and cost-effective to collaborate and look at stormwater management for larger areas. This approach could result in the adoption of more innovative strategies for new construction, appropriate retrofits in existing infrastructure, and the ability to use rainwater as a resource to work towards the Army's NZW goal. Ideally, a Stormwater Master Plan or Rainwater Resource Master Plan could be developed to foster creative solutions focusing on the NZW objectives.

Command Emphasis

Water use can be reduced significantly by users' actions alone. In addition, lack of knowledge about efficient water practices can counteract the most efficient technologies. Command awareness programs begin at the top and extend throughout the organization. Water conservation awareness efforts should involve collaboration with organizations outside the Army installation. A public information program should inform installation personnel of opportunities to reduce water use, provide the reasons why they should conserve, and publicize conservation options.

Command support

Net Zero Water installations are supported by the foundation provided by strong command support. Garrison Commanders chair the installation water council and use every opportunity to mention the importance of efficiency and conservation. Effective Commanders use the garrison Public Affairs Office resources and the full range of media outlets. Commanders can foster community relationships by participating in regional events related to water resources, for example, World Water Day or beach clean-ups.

Water awareness programs

A water awareness program will strive to reach every person on the garrison. All available media will be used including news outlets, signage, and a "hotline" for waste reporting. A building water monitor program can provide eyes and ears on the ground. Recognition programs are key to success. Awareness programs offer opportunities for partnering as can be seen with Fort Huachuca's Water Wise and Energy Smart Program (WWES). This program includes conservation, public outreach, youth education, water use audits, conservation tips, and information about landscaping (University of Arizona 2011).

Education

A formal water management education program is necessary to inform all those who affect installation water use, which is everyone who lives, works on, or visits an installation. The program should target each specific audience: soldiers, DPW/contractors, family members, and visitors. Special training should be provided for maintenance staff and for building water monitors.

Collaboration with other organizations

The nature of water as a regional resource points to the need for collaboration with others to safeguard supplies and optimize efficiency. The legal right to water is determined in each state and installations must be aware of their legal standing and also maintain an active relationship with the governing organization, e.g., State Environmental Office.

Code organizations will affect the types of technologies that may be adopted, therefore, continued dialogue with national, state, and local code groups will ensure that installation staff have the latest information. These groups are also interested in user feedback so dialogue should be two-way.

Management of water on a watershed basis requires knowledge of all demands. Other major regional water users should be considered for partnering. Collaboration with others supports long-term availability of regional water resources for the installation.

Sustainable Procurement should be used to support water programs. An interim rule amends the Federal Acquisition Regulation (FAR) to implement EO 13514 and EO 13423. Agencies will be required to foster markets for sustainable technologies, products, and services. They will also be required to implement high performance buildings in acquisition. In addition, contractors will be required to support the goals of an agency’s environmental management system (Federal Register 2011).

Recommendations

Command emphasis addresses the water use that can be affected by user actions alone. Some estimates place this as high as 30 percent of building water use. A comprehensive program of command support, awareness, education, and collaboration with other organizations is necessary to eliminate water waste. Resources are available from a wide variety of sources ranging from government (Department of Energy, Environmental Protection Agency, Department of Interior, states, universities), to non-profits (Alliance for Water Efficiency) and consultants. The Army could streamline the process for installations by developing a set of guidelines and recommendations for a command emphasis program in support of NZW.

Planning

Planning is a critical component of an installation Net Zero Water program. Installations currently prepare/possess multiple plans and studies related to water systems to include Water Management Plans, Safe Yield Studies, Water Quality Studies, Water System Vulnerability Assessments/Emergency Response Plans, Comprehensive Energy and Water Master Plans, and Environmental Impact Assessments that include water evaluations. Including information gleaned from these individual documents in installation-wide plans would support a stream-lined process of planning toward achieving NZW.

Army master planning

Installation water planning needs to be a part of the overall Master Planning process. Area Development Plans are used to ensure consistency in buildings and grounds in an area. There are several topics related to water sustainability that could benefit from inclusion in Area Development Plans and other master planning documents. These could be included as overlays so that they would be developed and considered in concert with other planning efforts.

An installation stormwater management plan addresses retention of stormwater on-site. It identifies locations that are appropriate for retention and includes details of low-impact design strategies that minimize the need for large-scale retention. It also identifies opportunities for rainwater collection and reuse, which can be adjacent, but not necessarily within the same building. A landscaping plan includes native species appropriate for different buildings/sites/ areas.

Where turf grass is required, such as parade grounds or sports fields, the plan identifies potential sources of sustainable water (rainwater, stormwater, condensate, or graywater).

Planning for water efficiency/conservation projects

Planning, prioritization, and execution of water projects requires the same process and oversight as project planning in general. Projects should be identified for near term (1 to 3 years), mid-term (3 to 5 years), and long term (more than 5 years) execution. Planners must understand and consider the trade-offs between water and energy. Many water efficiency opportunities require planning within systems (versus buildings) and across systems. Project execution programs need a method to balance; they must consider more than only return on investment. For example, it is important to consider preferential funding for water projects and infrastructure projects in addition to building projects. In addition, issues that may ordinarily be considered externalities (environmental impacts, ecosystem services) should be included and quantified as benefits in any cost-benefit analysis.

Some existing programs and tools

Regional planning for water security

Regional water sustainability assessments were conducted at 15 Army installations from 2009-2010. These studies prepared regional water budgets considering water supply and demand. In addition, forecasts of relative supply and demand were projected for a 30-year period based on a set of alternate future scenarios. Results showed a number of study installations that are vulnerable to an uncertain water supply future. Projected impacts include declining aquifers, reduced surface water flows, increasing regional demand, and the potential for disputes related to water rights.

Installation water demand tool

The Installation Water Demand Tool, developed as part of the regional studies described above, can be used by installations to project future demand for potable water. This tool predicts the capacity, demand, and water supply requirements for an Army installation over a 30-year horizon. The model works on the premise that there are three basic categories of water consumers on the installation, residents, commuters, and processes. The factors for the consuming sectors of the model were taken from Forecasting Urban Water Demand (Billings and Jones 2008). Sector demands were developed based on typical water consumption values and were calibrated to the installation's footprint, population, and op-tempo. Input can be tailored to account for increasing efficiency of buildings or changes in population.

Comprehensive Energy and Water Master Plan (CEWMP)

The Army's Installation Management Command (IMCOM) established a program for developing CEWMPs. CEWMPs are the roadmap for installations to achieve the provisions and recommendations of the Federal policy related to water efficiency and management. The Huntsville Installation Support Center of Expertise (ISCX) manages the program, which is carried out by contractors.

The steps in developing a CEWMP include conducting a visioning workshop, assessing existing conditions, creating a water profile, developing a water vision, developing a water action plan, outlining a capital investment strategy, and creating future focus/long range view of energy and water initiatives (US Army 2008).

At the time of this writing, 44 installations were listed on the CEWMP web site. Plans for Fort Hood, TX, Fort Irwin, CA, Fort Jackson, SC, Presidio of Monterey, CA, and Rock Island, IL are available through URL: https://eko.usace.army.mil/usacecop/is/fa/arpmp/hncppsupport/

Installation water management plans

Water management staff are responsible for maintaining installation-specific plans that detail water policy and define contingency plans for water conservation during periods of drought. Plans typically include installation water goals, historic water use and cost, water system description, analysis of water conservation projects, and implementation plans. Drought management plans can include time of day or alternating day landscape irrigation restrictions, limiting car washing, or total bans on these activities until adequate reserves are restored.

Recommendations

Many programs and tools are available to installations to support NZW planning efforts. The Army should continue the trend of embedding sustainability in the master planning process by including elements of Net Zero Water in existing plans and programs.

Recommendations

Net Zero water installations

Army installations are located in regions that encompass a broad spectrum of conditions that affect water security, cost, and applicability of water efficient technologies. The criteria that should be considered both in developing a definition of NZW, establishing metrics, and in prioritizing NZW installations include regional hydrologic conditions, installation water consumption, and per unit water cost. A NZW program on the installation should be unique and tailored to the characteristics above. Some policies, programs, and technologies will be applicable Army-wide and others are uniquely applicable.

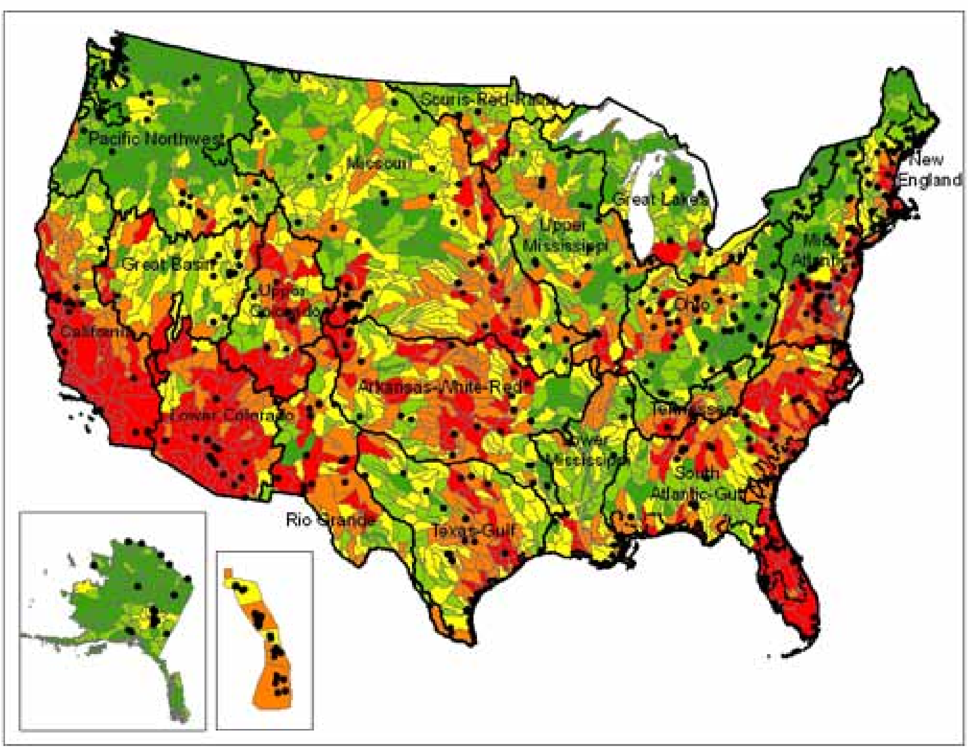
Hydrologic conditions: The regional watershed assessment

A regional watershed assessment evaluated overall watershed health for 2262 HUC8 watersheds. The national map of Army installations was overlaid to shown alignment of Army installations with their primary watersheds. Figure 8 shows the national map of watershed health with Army installations. Individual indicator maps are also available for the 17 indicators related to water supply and 10 indicators related to water demand.

This information could be used to prioritize installations for attainment of NZW. For example, an installation located in a region that is water stressed may be in need of a concentrated water conservation effort that NZW affords. Additionally, an installation located in a region with ample rainfall may have a high probability of success in achieving NZW.

Installation mission

The amount of water used on Army installations varies widely. Sometimes this is due to mission; for example, industrial sites require large amounts of water both for process and for fire protection. These facilities in particular, while they represent a large target, may be difficult to include in NZW programs. In many cases, the industrial processes are governed by USEPA regulations, sometimes "grandfathered" under older requirements. Any change in industrial processes could bring a facility in violation of current regulations and eliminate the "grandfather" status. Additional water-intensive missions include training sites that require water for dust suppression.



Source: Jenicek et al. (2005).

Figure 8. A national map of overall watershed health showing Army installations.

Weather conditions

Regional weather variations affect the amount of water required by installations. Regions with extended periods of high temperature will require additional cooling along with the water required to support cooling systems. Evapotranspiration rates are also higher in warmer regions meaning that more water will be lost during irrigation and vehicle washing. In addition to current weather patterns, projections for climate change should be taken into account when planning for NZW. For example, some regions are expected to receive less precipitation in the future. Others will receive similar amounts of precipitation, although it may arrive in the form of large storms interspersed with periods of drought. Installations located in regions that are vulnerable to the effects of climate change on water (drying soils, reducing reservoirs of surface water, reduced recharge to aquifers, increased flooding and drought, reduced snowpack, and earlier snowmelt) should consider early adoption of NZW.

Installation water use

Installation water use for 2010, as reported in the Army Energy and Water Reporting System (AEWRS) by 112 active installations, varies from a high of 1860 Mgal (7040 m^3) for US Army Garrison (USAG) Hawaii to a low of 6.5 Mgal (24.6 m^3) for Shinnen, Netherlands. Most installations range between 400–800 Mgal (1514–3028 m^3). When adjusted for square footage, as current water reduction targets require, consumption varies from a high of 278.6 gal/KSF (11.3 L/$m^{2)}$ for Radford Army Ammunition Plant to a low of 6.5 gal/KSF (0.26 L/m^2) for Shinnen (AEWRS 2011). Absolute or relative water consumption could be used as an input to evaluating installations' NZW potential.

Water cost assessment

DA installations used over 41.8 billion gallons (158 million m^3) of potable water at a cost of $67.4M in FY10 (DA 2011). (This equates to an average unit cost of $1.61/kgal [$2.35/m^3].) Although the cost on average is quite low, installation water rates vary regionally and sometimes seasonally. Higher rates are found in California ($10.01 at the Presidio of Monterey) and in the National Capital Region, where rates fall in the $3–$5/kgal ($0.79–$1.32/m^3) range with some seasonal rates (AEWRS 2010). The reported water rates at many installations reflect only the cost to pump and treat the water to potable standards if the installations are self-supplied, usually from groundwater wells. Implementation of NZW at Army installations could be prioritized at installations where water rates are relatively high and projects could amortize competitively.

Climate change projections

One-third of the Army's troops are stationed in the drought-prone Southeast. Another third are located in states with arid climates. Army installations have experienced the effects of regional water scarcity. Several installations have defended their water supplies from other local demands. Recent studies examined issues of supply and demand at 15 installations located in a diverse array of geographic, hydrologic, and geopolitical environments. These studies projected regional supply and demand over a period of 30 years under a series of alternate future scenarios. Inputs to the scenarios include climate change projections, population and industrial change, technologies, and extra-regional demands. Relevant climate inputs include temperature, precipitation, streamflow, and evapotranspiration.

Results of these studies point to an array of climate-driven effects that could affect water security both for the installations and the regions. Climate change is projected to exacerbate water scarcity in arid regions and affect availability in historically wet regions. The Army should take a proactive approach in planning for sustainable water supplies, particularly for installations that will experience the greatest climate-driven effects.

Net Zero Water strategies: Policy, programs, and technologies

Net Zero Water installations will require a tiered approach of policy, programs, and technologies. Mandatory provisions and prescriptive provisions will vary for different installations. Some technologies are appropriate for every installation, e.g., plumbing fixtures and appliances. Other technologies apply on a regional basis, e.g., HVAC condensate collection that is applicable in regions with high levels of relative humidity. Rainwater collection is useful only in regions with adequate rainfall to justify the system. Other technologies are difficult to install in existing buildings yet could be cost effective and appropriate for new construction. The following is a summary of recommendations made throughout this paper:

- The criteria for evaluating an installation's success at achieving Net Zero Water should be as diverse as the program that will be required for success. Metrics for NZW will be relative depending on enabling and limiting factors of hydrology, mission, climate, state water laws, applicable codes, historic water use, water cost, and climate change projections. Evaluation areas should include metrics related to water intensity, unaccounted for water, landscape irrigation, alternate water, site water, water balance, and command emphasis.

- The condition of water distribution systems on Army installations is similar to that of the United States at large in design and pipe age. Improvements in metering and leak detection are necessary to reduce water loss. While standards for technical performance, increased efficiency, and reduced use have been implemented, no such standards exist for leak detection or repair. System monitoring and repair must start with a plan that prioritizes high risk and critical survey zones while establishing a survey routine that encompasses the entire system. This should include routine checks of older or higher risk pipes. Comprehensive leak detection must be done with a combination of detection technologies intended to reduce survey time and address the varied inventory of pipe systems. Similarly, selection of pipe repair technique will be based on location and pipe status. Water meters can be installed strategically to provide the most information on system condition while helping detect and assess water loss. The key to water distribution system monitoring and maintenance is vigilance and proactive measures.
- HVAC systems account for a significant percent of water loss on an installation. Criteria for new buildings and major renovations include water-efficient technologies. A large impact in water loss prevention can be made through adopting a comprehensive and rigorous inspection and maintenance program for these systems. Graywater and condensate should be used, to the extent practicable, and legally permissible, for cooling towers and any remaining once-through cooling. Any replacements and upgrades should adhere to the water conservation requirements contained in the Whole Building Design Guidelines.
- Advanced drinking water treatment systems can purify otherwise undrinkable water thereby increasing available water. This is sometimes at the cost of higher energy consumption so these two resources need to be examined together.
- Wastewater treatment has the potential to serve as a primary source for alternate water on the installation. Tertiary treated wastewater can be used on-site for irrigation, dust suppression, and cooling tower make-up. In addition, this water can be used to replenish local groundwater sources. Installations should follow FEMP's recommended process to help determine whether purchased or on-site reclaimed water is appropriate. Likewise, decentralized wastewater treatment as an option for providing a local source of reclaimed water and reducing energy usage will require detailed studies.
- The three factors that present challenges in the near future with implementing graywater reuse are technology, regulatory, and maintenance. Technology consensus standards are still under development meaning that systems now on the market have not met the rigorous testing that such standards impose. Additionally, technological immaturity and limited market penetration result in relatively high first costs. Differing code requirements require that these technologies must be evaluated on a case-by-case basis unique to the locale. Rigorous maintenance is imperative to ensure that health and safety are not compromised. This obstacle can be overcome through the use of maintenance contracts. Decentralized, building-level graywater reuse poses challenges. An installation must be aware of the economic considerations, installation, management, oversight, monitoring, and maintenance needed to maintain these systems and prevent cross contamination.
- Water efficient appliances and fixtures are some of the easiest conservation retrofits to accomplish. EPAct 2005, EISA 2007, E.O. 13423, and E.O. 13514 require Federal agencies to achieve water reduction targets and improve water efficiency by incorporating BMPs and through the use of water-efficient products and services. Replacing fixtures and appliances wherever possible is a guaranteed route to water savings. In particular, devices that use hot water will show a quicker payback due to energy savings. There are several tools available on line to calculate the savings in water, energy, and cost due to retrofits or replacements. These calculations, using installation-specific data, will provide the most accurate assessment and help in prioritizing upgrades. While the criteria specifies a maximum flow, a range of flows are available for some fixtures and appliances. It is important to ensure that user needs are met while achieving the greatest savings possible. *WaterSense®* labeled devices have been tested for efficacy as well as efficiency. Some super-saver appliances may be well worth the investment to decrease water use even further.
- Reducing or eliminating landscape irrigation is a quick and relatively simple solution to a major water demand on installations. Installations may choose to use rainwater, graywater, condensate, or reclaimed water to irrigate gardens or landscaping. Smart irrigation controls can be used to provide adequate amounts of water to sustain vegetation at the optimum time of day. For new areas or those under renovation, planting native species will limit water requirements beyond that required to establish plantings.
- The new principles of LID focus on controlling withdrawals at the source with micro-scale controls scattered throughout the site. Despite the challenge and high expense of storm water management on small sites, installations often require this. Existing standards may impede or prevent application of LID principles; flexibility would facilitate sustainable design and development efforts that meet Army sustainability and energy mandates. A bigger issue for successfully meeting the EISA re-

quirement is the definition of the "Site" boundaries. Ideally, a Stormwater Master Plan or Rainwater Resource Master Plan could be developed to foster creative solutions focusing on the net zero water objectives.

- The Army has a number of initiatives that seek to privatize functions that were historically executed by civil service employees. It is critical that any contracts that affect water consumption on Army installations include provisions for conservation and efficiency. These include contracts for utility privatization, maintenance and repair, water purchase contracts, and the Residential Contracting Initiative. Sustainable Procurement should be used to support water programs in accordance with the recent interim rule amending the Federal Acquisition Regulation to achieve high performance buildings and requiring contractors to support the environmental management system.
- Command emphasis addresses the water use that can be affected by user actions alone. A comprehensive program of command support, awareness, education, and collaboration with other organizations is necessary to eliminate water waste. Command awareness programs begin at the top and extend throughout the organization. Water conservation awareness efforts should involve collaboration with organizations outside the Army installation. The Army could streamline the process for installations by developing a set of guidelines and recommendations for a command emphasis program.
- Planning is a critical component of an installation Net Zero Water program. Installations currently prepare/possess multiple plans and studies related to water systems to include Water Management Plans, Safe Yield Studies, Water Quality Studies, Comprehensive Energy and Water Master Plans, and Environmental Impact Assessments that include water evaluations. Including information gleaned from these individual documents in installation-wide plans would support a stream-lined process of planning toward achieving NZW. The Army should continue the trend of embedding sustainability in the master planning process by including elements of NZW in existing plans and programs.

Conclusions

The concept of achieving Net Zero Water is new territory that the Army is exploring, thus the limited number of examples. In addition, there are special challenges with adapting existing facilities/infrastructure. The Army is in the unique position of maintaining a high degree of control over city-like campuses. This positions the Army to be involved in acquisition, treatment, distribution and use —and potentially reuse— in a holistic fashion, an opportunity that few organizations are afforded.

Given this significant opportunity, partnering will be the key. Some water management functions are already privatized, whatever we do affects others in the watershed and regulators, and the Army needs to have "end users" fully engaged in whatever solutions we select and implement. There are state and regional players, code groups, national industry associations, and other Federal entities.

There are few truly new technologies that are applicable to water efficiency and conservation programs. However, there is a lack of information for many technologies on effectiveness, return on investment, maintenance, and other life cycle implications. It is imperative that the Army document not only its own technology demonstrations, but also collect the "lessons learned" from others to assist installations in planning and investment toward attainment of NZW.

Large reductions in water use will require taking a holistic approach that includes policy, technology, education, partnering with others, and strong command emphasis, however, some initiatives will be applicable Army-wide while others are uniquely applicable. Consideration should be given for varying circumstances between and among Army installations that may affect water supply and demand. Army installations are located in regions that encompass a broad spectrum of conditions that affect water security, cost, and applicability of water efficient technologies. The criteria should include regional hydrologic conditions, installation water consumption, and water cost.

Hydrologic conditions vary across the United States and include differences in surface and groundwater availability and vulnerability to drought and other climate extremes. Climate conditions will affect the potential applicability of some NZW technologies, e.g., collection of rainwater and condensate. Local laws and codes will also affect technology infusion e.g., the legality of collecting rainwater and the codes regulating graywater reuse. Finally, installations themselves vary in the maturity of water conservation programs, some having already achieved substantial savings and perhaps not easily able to further reduce consumption. A Net Zero Water program on the installation should be unique and tailored to these characteristics.

References

2030 Water Resources Group. Charting Our Water Future: Economic frameworks to inform decision-making. The Barilla Group, The Coca-Cola Company, The International Finance Corporation, McKinsey & Company, Nestle S.A., New Holland Agriculture, SABMiller plc, Standard Chartered Bank, and Syngenta AG. 2009.

American Society of Civil Engineers (ASCE). 2009. Report card for America's infrastructure. Accessed 10Aug2010, http://www.infrastructurereportcard.org/fact-sheet/wastewater

American Water Works Association (AWWA) and Raftelis Financial Consultants, Inc. 2009a. 2008 Water and wastewater rate survey. Denver, CO: AWWA.

———. 2009b. Water audits and loss control programs. AWWA Manual M36. Denver, CO: AWWA.

Army Energy and Water Reporting System (AEWRs). 2011. Army installation water consumption data. Accessed 7 February 2011, https://aewrs.hqda.pentagon.mil/aewrs/

———. 2010. Army installation water cost data. https://aewrs.hqda.pentagon.mil/aewrs/ Accessed 12 March 2011.

Australian/New Zealand Standards (AS/NZS) 3500.2a. Amendment, 11.24.2.3

———. AS/NZS 3500.2b. Amendment, 4.9.3

Balocki, James. 22 May 2008. Army growth and BRAC update. Presentation given at the 2008 Society of American Military Engineers Conference, Minneapolis, MN.

Bandy, John T., and Richard J. Scholze. 1983. Distribution of Water Use at Representative Fixed Army Installations. Technical Report N-157. Champaign, IL: Construction Engineering Research Laboratory.

Bar, Etan. 2004. Extraction of water from air-an alternative solution for water supply. Desalination 164:335.

Billings, R. B., and C. V. Jones. 2008. Forecasting urban water demand. Denver, CO: AWWA.

Brekke, Levi D., J. E. Kiang, J. R. Olsen, R. S. Pulwarty, D. A. Raff, D. P. Turnipseed, R.S. Webb, and K. D. White. 2009. Climate change and water resources management: A Federal perspective. Circular 1331. Reston: US Department of the Interior, US Geological Survey, http://www.usgs.gov/pubprod

Building Design and Construction. November 2009. Water Performance: Getting the Most from Every Drop. Published in Building Design & Construction, http://www.bdcnetwork.com/

Building Products News. 2010. Accessed 7 December 2010, http://www.bpn.com.au/

Carlson, Ann. 16 April 2010. Unintended Consequences and Environmental Policy. Legal Planet, http://legalplanet.wordpress.com/2010/04/16

Chesnutt, T., G, Fiske, J. Beecher, and D. Pekelney. 2007. Water efficiency programs for integrated water management. Denver, CO: Water Research Foundation.

Clark, Jeff. Undated. Australasian scientific review of reduction of flows on plumbing and drainage systems. Presentation. ASFlow.

Clear Environmental. 2008 Oberlin College going green. Accessed 31 July 2008, http://clearenvironmental.wordpress.com/tag/green-guilding/

Cumings, Steve. 2008. Future directions for water efficient fixtures and drainage systems in Australia. Presented at Water Smart Innovations. October 2008. Las Vegas, NV.

DefenseNews.com. 2011. Gates: $400 Billion From DoD Budgets 'Not A Minor Cut.' Accessed 16 June 2011, http://DefenseNews.com

Department of the Army (DA). 2011. Army Annual Energy and Water Report. Washington, DC: Headquarters, Department of the Army (HQDA).

———. 27 October 2010. Sustainable Design and Development Policy Update (Environmental and Energy Performance). Washington, DC: Office of the Assistant Secretary of the Army, Installations, Energy and Environment.

Duffy, Maureen. 2009. Water Reuse. White Paper. Voorhees, NJ: American Water.

East Bay Municipal Utility District (EBMUD). 2010. Water Conservation Market Penetration Study. Final Report. San Francisco, CA: Water Resources Engineering, http://www.ebmud.com/sites/default/files/pdfs/market_penetration_study_0.pdf

Environmental Security Technology Certification Program (ESTCP). 2011. Water conservation: Tertiary treatment and recycling of waste water. Fact Sheet. Accessed 19 May 2011, http://www.estcp.com/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/ER-201020

Epstein, Kyra, Russell Albanese, Michael Gubbins, and Adam Hinge, P.E. 2008. "NYC's Living Lesson." High Performing Buildings. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

Federal Energy Management Program (FEMP). June 2010. Methodology for use of reclaimed water at Federal locations. PNNL-SA-73577, http://www.eere.gov/informationcenter

Federal Register Online. 2011. FR Doc No.: 2011-12851, Federal Acquisition Regulation; Sustainable Acquisition. Government Printing Office. . Accessed 9 June 2011, http://www.gpo.gov/fdsys/pkg/FR-2011-05-31/html/2011-12851.htm?CFID=4654540%20&CFTOKEN=57186059

George, Ron. 2010. Water Conservation Efforts Unwittingly Leading to 'Dry Drains.' Plumbing Engineer. June Northbrook, IL: TMB Plumbing Engineer.

Hall, N. and B. B. Stuntz. 2009. US water stewardship: A critical assessment of interstate watershed agreements. Watermark Initiative.

Hallahan, Dennis. 2010. "The Use of Onsite Wastewater Treatment Systems in Concert with Water Reclamation and Reuse." Water Efficiency. November-December 2010.

Henderson, Hartley. 2010. "Too Green, Too Fast: Dry Drains." Facility Management, http://www.fmmagazine.com.au/green-zone/too-green-too-fast-dry-drains/

Hoffman, H. 2008. "Capturing the water you already have: Using alternate onsite sources." Journal of the American Water Works Association. Denver, CO: AWWA.

Institute of Electrical and Electronic Engineers (IEEE). June 2010. The Coming clash between water and energy. IEEE Spectrum. Washington, DC: IEEE.

Interface Engineering. Undated. Achieving Net-Zero Water. Presentation, http://www.interfaceengineering.com

International Living Building Institute. 2011. Accessed 22 March 2011, http://ilbi.org/lbc

Jenicek, Elisabeth M., Rebecca A. Carroll, Laura E. Curvey, MeLena S. Hessel, Ryan M. Holmes, and Elizabeth Pearson. March 2011. Water Sustainability Assessment for Ten Army Installations. Technical Report. ERDC/CERL TR-11-5. Champaign, IL: ERDC/CERL.

Jenicek, Elisabeth M., Natalie R.D. Myers, Donald F. Fournier, Kevin Miller, MeLena Hessel, Rebecca Carroll, and Ryan Holmes. September 2009. Army installations water sustainability assessment: An evaluation of vulnerability to water supply. Technical Report. ERDC/CERL TR-09-38. Champaign, IL: ERDC/CERL.

Jenicek, Elisabeth M., Donald F. Fournier, Natalie R. Downs, and Brad Boesdorfer. September 2005. Watershed Application of the Sustainable Installations Regional Resource Assessment Tool. ERDC/CERL TR-05-24. Champaign, IL: ERDC/CERL.

Jenkins, Jesse, Ted Norhous, and Michael Shellenberger. 2011. Energy Emergence: Rebound & backfire as emergent phenomena. Breakthrough Institute, http://thebreakthrough.org/blog/2011/02/new_report_how_efficiency_can.shtml

Johnson, Kirk. 28 June 2009. "It's Now Legal to Catch a Raindrop in Colorado." New York, NY: New York Times.

Johnson, Paul W., and Earl H. Stockdale. 24 November 1995. Policy Guidance on Water Rights at Army Installations in the United States. Washington, DC: DA, Office of the Assistant Secretary Installations, Logistics, and Environment.

Karl, Thomas R., Jerry M. Melillo, and Thomas C. Peterson (eds.). 2009. Global Climate Change Impacts in the United States. Cambridge, UK: Cambridge University Press.

Kenny, J. F., N. L. Barber, S. S. Hutson, K. S. Linsey, J. K. Lovelace, and M. A. Maupin. 2009. Estimated use of water in the United States in 2005. US Geological Survey Circular 1344. Reston, : US Geological Survey (USGS).

Lawrence, Thomas, and J. Perry. 2010. "Capturing Condensate." High Performance Buildings. Atlanta, GA: ASHRAE. Fall 2010.

Lepisto, Christine. 10 July 2006. "WaterSaver Technologies Aquus Uses Sink Graywater for Toilet." New York, NY: Treehugger Design and Architecture.

Living Machines. 2011. Accessed 22 March 2011. http://www.livingmachines.com/

Lovins, Amory. 17 January 2011. Reply to "The Efficiency Dilemma." The New Yorker, http://rmi.org/rmi/Library/2011-01_ReplyToNewYorker

Madungwe, E., and S. Sakuringwa. 2007. Greywater reuse: A strategy for water demand management in Harare? Physics and Chemistry of the Earth. Elsevier Ltd.

Martin, Shawn. 2010. Residential Graywater Reuse – A Technology Whose Time Has Come? International Code Council. Presentation at Water Smart Innovations. Las Vegas, NV. 7 October 2010.

McKeown, Alice, and G. Gardner. 2009. Climate change reference guide. Update to State of the World 2009: Into a Warming World. Washington, DC: Worldwatch Institute.

National Climatic Data Center (NCDC). 2011. US Climate Regions. Accessed 17 May 2011, http://www.ncdc.noaa.gov/temp-and-precip-us-climate-regions.php

National Oceanic and Atmospheric Administration (NOAA). 2009. NOAA online weather data, http://www.weather.gov/climate/

Pacific Northwest National Laboratory (PNNL). 2011. Energy Code Climate Zones. Accessed 17 May 2011, http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter

Plumbing Manufacturers Institute (PMI). 2010. U.S.A.'s Plumbing Efficiency Research Coalition (PERC) and the Australasian Scientific Review of Reduction of Flows on Plumbing and Drainage Systems (ASFlow) to sign MoU at U.S. EPA headquarters, Press Release, http://archive.pmihome.org/pressroom/PR_120310.aspx

Postel, Sandra. 1999. Pillar of Sand-Can the Irrigation Miracle Last? New York, NY: W.W. Norton & Company.

Reilly, T. E., K. F. Dennehy, W. M. Alley, and W. L. Cunningham. 2008. Ground-water availability in the United States: US Geological Circular 1323, http://pubs.usgs.gov/circ/1323/

Rogers, E. 1992. Diffusion of Innovations. New York, NY: The Free Press.

———. 1983. Diffusion of Innovations. 1st ed. New York, NY: The Free Press.

Rogers, John, and E. Spanger-Siegfried. 2010. The Energy-Water Collision. Catalyst. Cambridge, MA: Union of Concerned Scientists.

Romm, Joe (ed.). Climate Progress. Accessed 23 June 2011. http://thinkprogress.org/romm/2011/02/15/207530/the-breakthrough-institute-attack-energy-efficiency-clean-energy-backfire-rebound-effect/

Roy, Sujoy, B. L. Chen, E. Girvetz, E. P. Maurer, W. B. Mills, and T. M. Grieb. 2010. Evaluating sustainability of projected water demands under future climate change scenarios. New York: Natural Resources Defense Council.

Safe Drinking Water Foundation (SDWF). 2011. Ultrafiltration, Nanofiltration and Reverse Osmosis, http://www.safewater.org/PDFS/resourcesknowthefacts/Ultrafiltration_Nano_ReserseOsm.pdf. accessed 19 May 2011.

Scholze, Richard J., Gary L. Gerdes, William D. Goran, Kurt Preston, John Hall, David Sheets, and Richard Sustich. April 2009. Proceedings of the Military Applications for Emerging Water Use Technologies Workshop. Technical Report. ERDC/CERL TR-09-12. Champaign, IL: ERDC/CERL.

Science Daily. 29 September 2010. The Precious Commodity of Water, http://www.sciencedaily.com/releases/2010/09/100910130557.htm. Accessed 24Jun2011

Sturm, Reinhard, Paul Thomas, and Joone Lopez. 2010. The Link between Water Loss and Energy Consumption – Southern California Edison's Embedded Energy in Water Pilot. WaterSmart Innovations 2010. Las Vegas, NV. 6-8 October 2010.

Texas Commission on Environmental Quality (TCEQ). 2007. Harvesting, Storing, and Treating Rainwater for Domestic Indoor Use. January 2007(GI-366), http://rainwaterharvesting.tamu.edu/drinking/gi-366_2021994.pdf

Texas Water Development Board (TWDB). 2005. The Texas Manual on Rainwater Harvesting, 3rd Edition. Austin, TX, http://www.twdb.state.tx.us/publications/reports/rainwaterharvestingmanual_3rdedition.pdf

United Nations. 2000. 55/2 United Nations Millennium Declaration, http://www.un.org/millennium/declaration/ares552e.pdf. 18 September 2000

United Nations Environment Programme (UNEP). 2002. The Atlas of international freshwater agreements. Nairobi: UNEP, http://www.transboundarywaters.orst.edu/publications/atlas/

United Nations Educational, Scientific, and Cultural Organization (UNESCO) and International Association of Hydrogeologists (IAH). 2010. Internationally Shared Aquifer Resources Management Initiative (ISARM), http://www.isarm.net/

US Army, Assistant Secretary of the Army, Installations, Energy, and Environment (ASA(IE&E)). 2011. Army Vision for Net Zero: Net Zero is a Force Multiplier.

US Army, Headquarters. 2008 Comprehensive Energy and Water Master Plan: Methodology. Washington, DC: Headquarters, Department of the Army (HQDA).

US Army, Assistant Chief of Staff for Installation Management (ACSIM). Undated. FY 2010 Annual Energy Management Report.

———. 2011a. Army Energy Program Web Site, http://army-energy.hqda.pentagon.mil/netzero/default.asp. Accessed 22 March 2011

———. 2011b. Rescission of the Army Standard for Urinals. 28 March 2011.

———. 2008. Advanced Water Meter Specifications. Memorandum. http://army-energy.hqda.pentagon.mil/programs/metering.asp. 12 March 2008

———. 2006. Army Metering Implementation Plan. 6 September 2006.

US Army Installation Management Command (IMCOM). 2008. Potable Water and Waste Water Privatization Status. Presentation Slide 080900RAPR08, IMPW-E.

US Bureau of Reclamation. 2007. Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead. Accessed 9 June 2011, http://www.usbr.gov/lc/region/programs/strategies/FEIS/index.html

US Environmental Protection Agency (USEPA). November 2010. Control and Mitigation of Drinking Water Losses in Distribution Systems. USEPA 816-R-10-019. Washington DC: USEPA Office of Water, http://water.epa.gov/type/drink/pws/smallsystems/upload/Water_Loss_Control_508_FINALDEc.pdf

USEPA. February 2008. Emerging technologies for wastewater treatment and in-plant wet weather management. USEPA 832-R-06-006. Office of Wastewater Management. Fairfax, VA: USEPA, http://water.epa.gov/scitech/wastetech/upload/2008_03_13)mtb_emerging_technologies.pdf

USEPA. September 2002. The clean water and drinking water infrastructure gap analysis. EPA-816-R-02-020. Washington DC: USEPA.

US Government Accountability Office (USGAO). July 2003. Freshwater supply: States' views of how Federal agencies could help them meet the challenges of expected shortages. GAO-03-514, Washington, SC: USGAO.

University of Arizona. 2011. Fort Huachuca: Be Water Wise and Energy Smart. Accessed 2 June 2011, http://ag.arizona.edu/cochise/wwes/

Vickers, Amy. 2001. Handbook of water use and conservation: Home, landscapes, businesses, industries, farms. Amherst: WaterPlow Press.

World Economic Forum (WEF). 2008. Thirsty energy: Water and energy in the 21st century. WEF in partnership with Cambridge Energy Research Associates. Geneva: WEF.

World Health Organization (WHO) and United Nations Children's Fund (UNICEF). 2005. Water for life: Making it happen. Geneva: World Health Organization, http://www.who.int/water_sanitation_health/monitoring/jmp2005/en/index.html

Worrell Water Technologies. 2011. Living Machine Projects. Accessed 24 January 2011, http://www.livingmachines.com

Zahniser, David, Phil Willon, and Jessica Garrison. 2010. Lawn-watering rules contributed to L.A. main breaks, experts find, http://latimesblogs.latimes.com/lanow/2010/04/las-rash-of-water-main-breaks-caused-by-rationing-report-says.html. 13 April 2010

Zavoda, Michael. 2006. NYC high-rise reuse proves decentralized system works. Water and Wastewater International. 21(1). February 2006.

US Army Corps of Engineers®
Engineer Research and Development Center
Construction Engineering Research Laboratory

Contacts:

Elisabeth Jenicek, Principal Investigator
Phone: (217) 373-7238
e-mail: Elisabeth.M.Jenicek@erdc.usace.army.mil

Bill Goran, Technical Director
Phone: (217) 373-6735
e-mail: William.D.Goran@erdc.usace.army.mil

https://casi.erdc.usace.army.mil